The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

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American Volume

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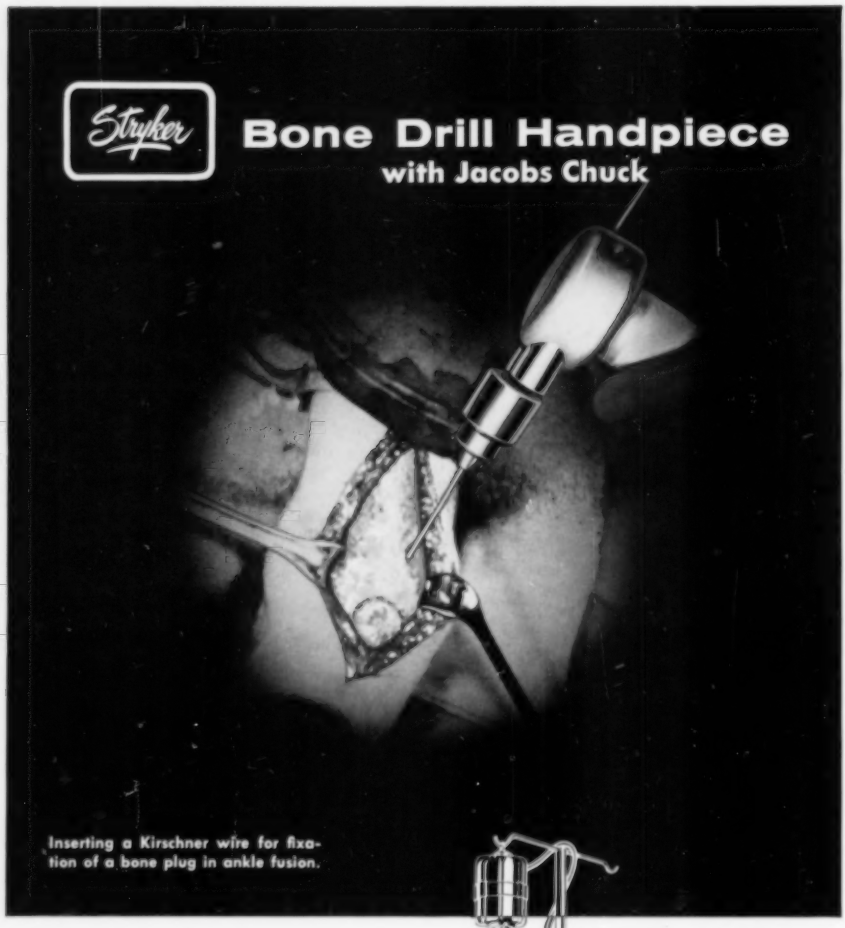

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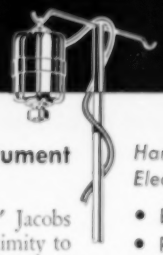

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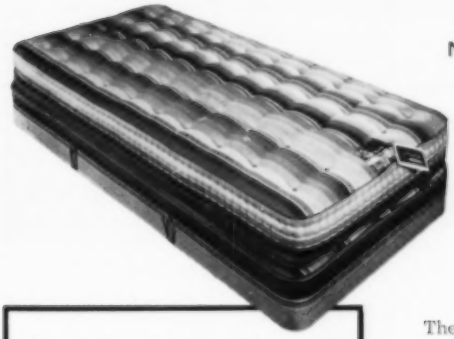

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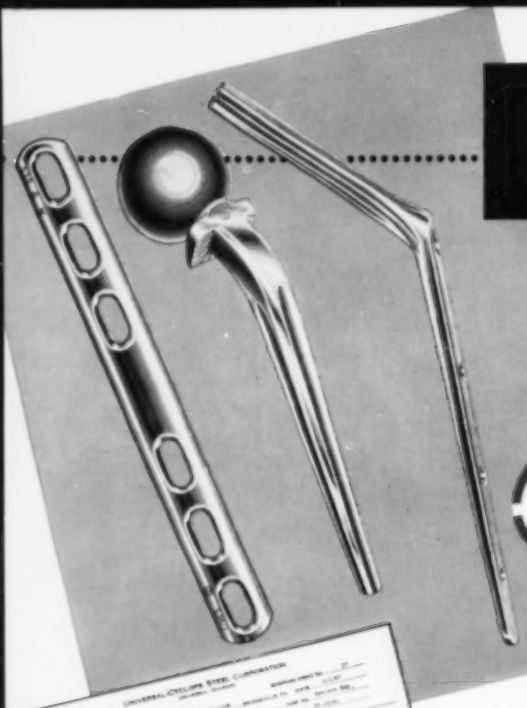

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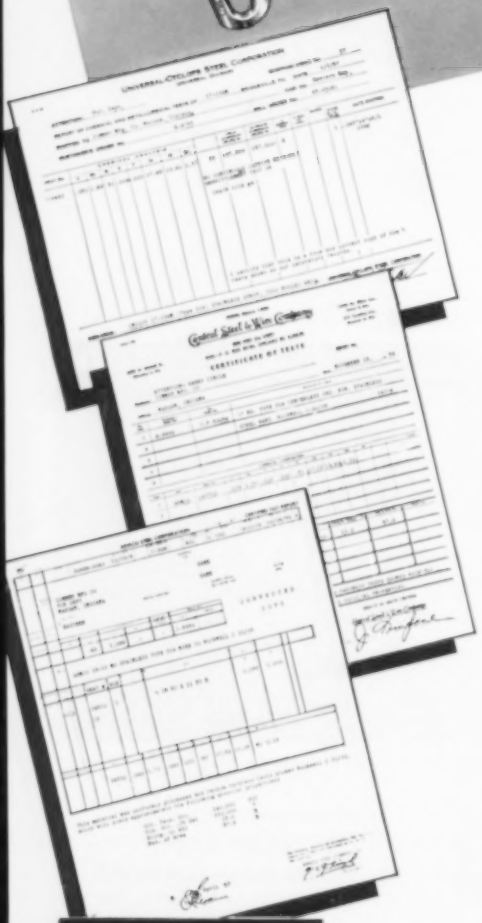

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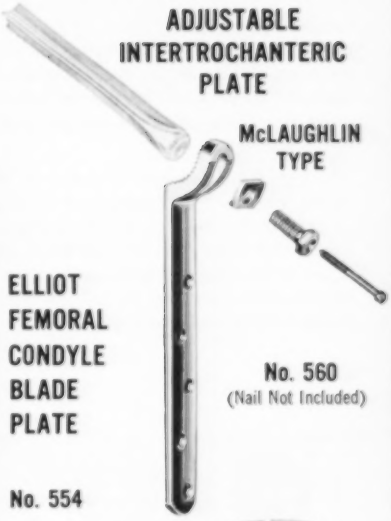

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2.

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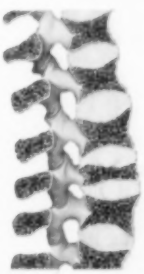

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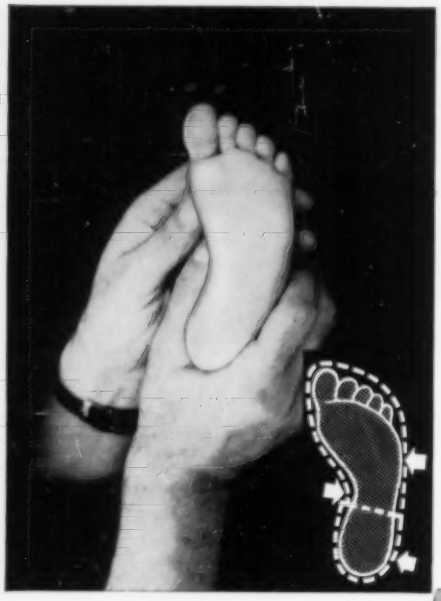

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When the hind-foot is held in a position of inward rotation, the talo-scaphoid and cuneiform-scaphoid joints will remain locked under weight bearing. The arch will not collapse and the ankle will not roll inward.

Correction is accomplished by the specially shaped last. Medially wedged and extended heels promote better weight distribution. Medially extended counters are used for utmost control.

See us in Chicago — January 24–29
26th Annual Meeting
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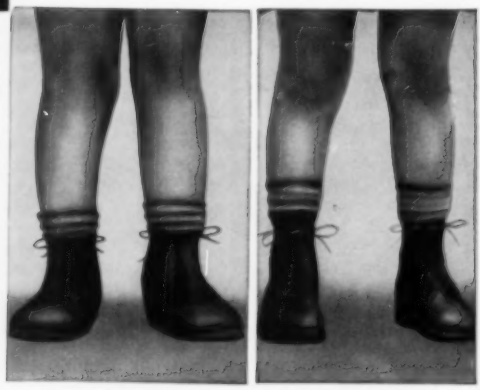

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Tarso Shoes are ready-made and are available on prescription from dealers in most cities. Write for catalog and name of nearest dealer.

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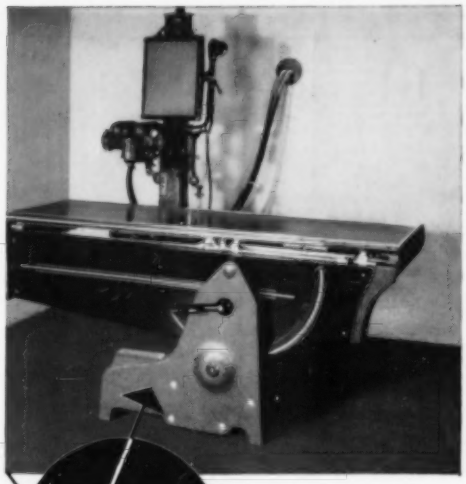

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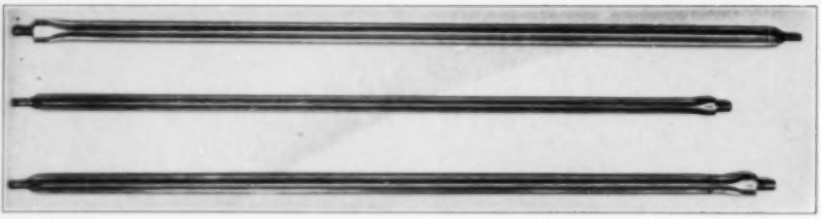
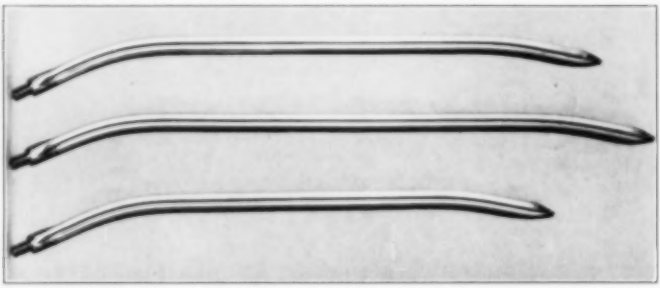
LOTTES NAILS and INSTRUMENTS



***LOTTES* FEMORAL NAILS** are manufactured with diameters of 3/8, 7/16, and 1/2 inches —with lengths in 1/2 inch variations from 14 to 20 inches.

***LOTTES* TIBIAL NAILS** are made in 5/16 and 3/8 inch diameters—in lengths from 9 to 15 1/2 inches, in variation of 1/2 inch.



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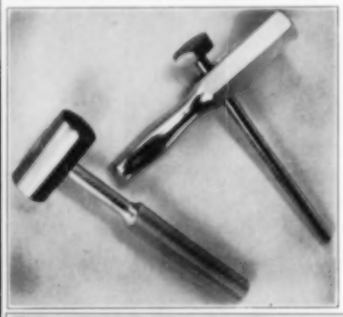

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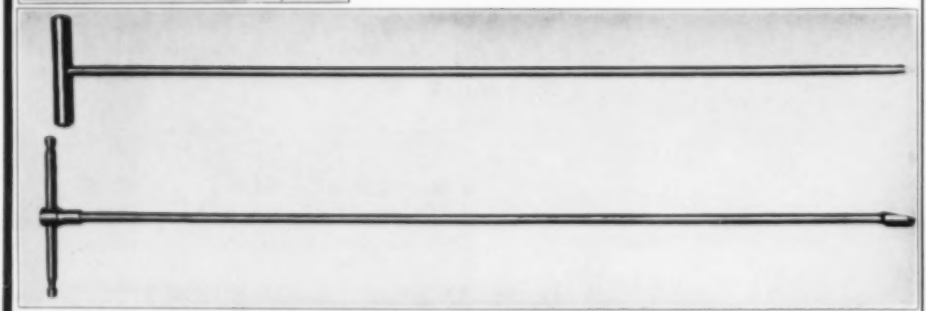

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CONTROLLED stability

Circular compression of the entire area covered is readily controlled by adjustment of the lacings . . .

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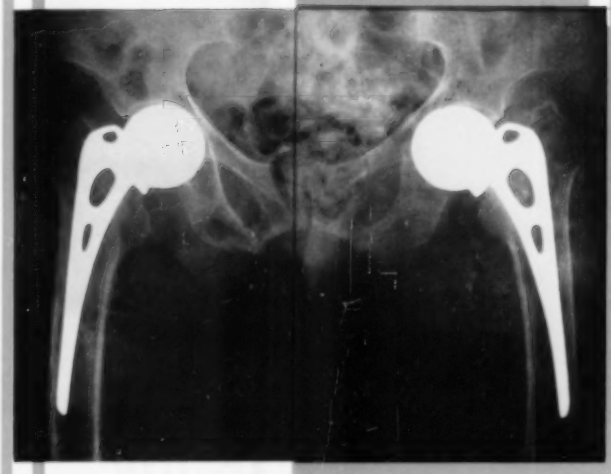
VITALLIUM® HIP PROSTHESES...

A PROGRESS REPORT



Roentgenogram of a bilateral arthroplasty utilizing Vitallium Moore prostheses.

"Most of the results are satisfactory, some are excellent. I am confident that they have been more successful than could be expected from any other reconstructive or arthroplastic procedure. With careful control, the prosthesis may give satisfactory service throughout the patient's lifetime."[1]

In 22 years of use, over 7,000,000 Vitallium appliances have been surgically implanted and there has never been one authenticated case of corrosion reported.

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- **Pathological Fractures**[1, 2, 4, 5, 7]
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- **Osteoarthritis**[1, 2, 5, 6, 9, 10]
- **Bilateral Ankylosis**[10]
- **Salvage**[6, 7, 9]

REFERENCES:

*1. Moore, A. T.: The Self-Locking Metal Hip Prosthesis. J. Bone & Joint Surg., **39A**:811,1957. 2. Symposium on Femoral Head Replacement Prostheses. J. Bone & Joint Surg., **38A**:407,1956. 3. Savastano, A. A., Sage, L. A., and Zecchino, V.: Treatment of Fractures of the Neck of the Femur with Intramedullary Stem Prosthesis. J. Bone & Joint Surg., **40A**:233,1958. *4. Mahoney, J. W. Mullholland, J. H., Jahr, J. and Dooling, J. A.: Immediate Moore Prosthetic Replacement In Acute Intracapsular Fractures. Am. J. Surg., **95**:577,1958. 5. Stinchfield, F. E., Cooperman, B. and Shea, C. W.: Replacement of the Femoral Head by Judet or Austin Moore Prosthesis. J. Bone & Joint Surg., **39A**:1043,1957. 6. Lippman, R. K.: The Transfixion Hip Prosthesis. J. Bone & Joint Surg., **39A**:759,1957. 7.. Ghormley, R. K.: The Present Status of Surgery of the Hip. Rocky Mountain M. J., **54**:337,1957. *8. Rowe, C. R., and Detwiler, R. C.: Fractures in the Aged. J.A.M.A., **162**:1517, Dec. 22, 1956. *9. Thompson, F. R.: Two and a Half Year's Experience with a Vitallium Intramedullary Hip Prosthesis. J. Bone & Joint Surg., **36A**:489,1954. *10. Moore, A. T.: Metal Hip Joint: A New Self-Locking Vitallium Prosthesis. South. M. J., **45**:1015,1952.

*REPRINTS OF THESE PAPERS AVAILABLE ON REQUEST.

VITALLIUM® HIP PROSTHESES IN THOUSANDS OF CASES PROVED SUCCESSFUL

Roentgenogram of a bilateral arthroplasty utilizing Vitallium Moore prostheses.

Moore's observation is one of many recent statements concerning treatment of the so-called "unsolvable fracture." Once considered the plague of the elderly, fractures of the hip can now be treated with less risk and shock than was believed possible just a few years ago.

"The indications for the use of prostheses appear to be becoming more clearly defined. Non-union, arthritis, and asceptic necrosis are almost universally accepted as indications, while the use of prostheses in fresh fractures of the femoral neck at any age, but in the aged particularly, is increasing."[2] "Use of the femoral-head prosthesis in fresh fractures, when indicated, may reduce the incidence of uraemia, hypostatic pneumonia and death."[3]

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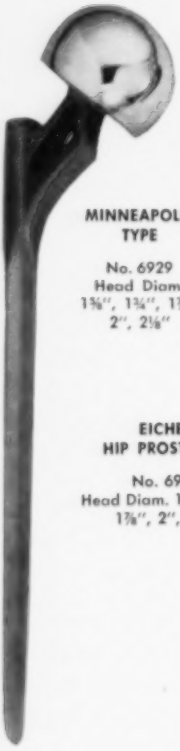
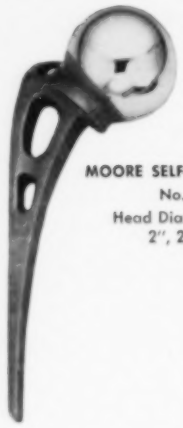


MINNEAPOLIS TYPE

No. 6929
Head Diam.
1⅝", 1¾", 1⅞"
2", 2⅛"



MOORE SELF-LOCKING HIP PROSTHESIS

No. 6939 Regular
Head Diam. 1½", 1⅝", 1¾", 1⅞",
2", 2⅛", 2⅜", 2¼", 2½"

MODIFIED MOORE HIP PROSTHESIS

No. 6939-1 Narrow stem
Head Diam. 1⅝", 1¾", 1⅞"

EICHER HIP PROSTHESIS

No. 6927
Head Diam. 1⅝", 1¾",
1⅞", 2", 2⅛"

F. R. THOMPSON HIP PROSTHESIS

No. 6936-1	Straight	1⅝" Head Diam.
6936-2	Straight	1¾" Head Diam.
6936-3	Left	1¾" Head Diam.
6936-4	Right	1¾" Head Diam.
6936-5	Straight	1⅞" Head Diam.
6936-6	Left	1⅞" Head Diam.
6936-7	Right	1⅞" Head Diam.
6936-8	Straight	2" Head Diam.
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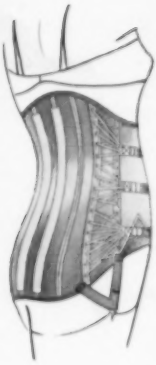

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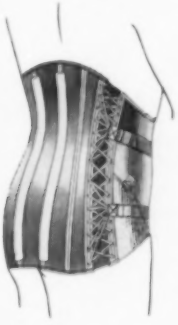
Support for Women



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Price without table with bracket for attaching to plinth,

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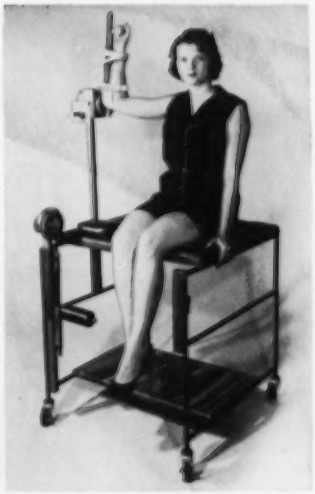

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Exercise arm built with Reversible Ratchet on Sensitive Pressure Plate offering any desired resistance calibrated in lbs. from 0 to 80. Range of motion indicator in full view of patient and therapist for accurately following Range Progress. Ideal for use with BK Amputees and BK Fractures, may also be used for Hamstring Exercise, Hip Abduction and Extension. Complete unit including table 28 x 30 x 32 with Quadriceps Rest, Model # 9950

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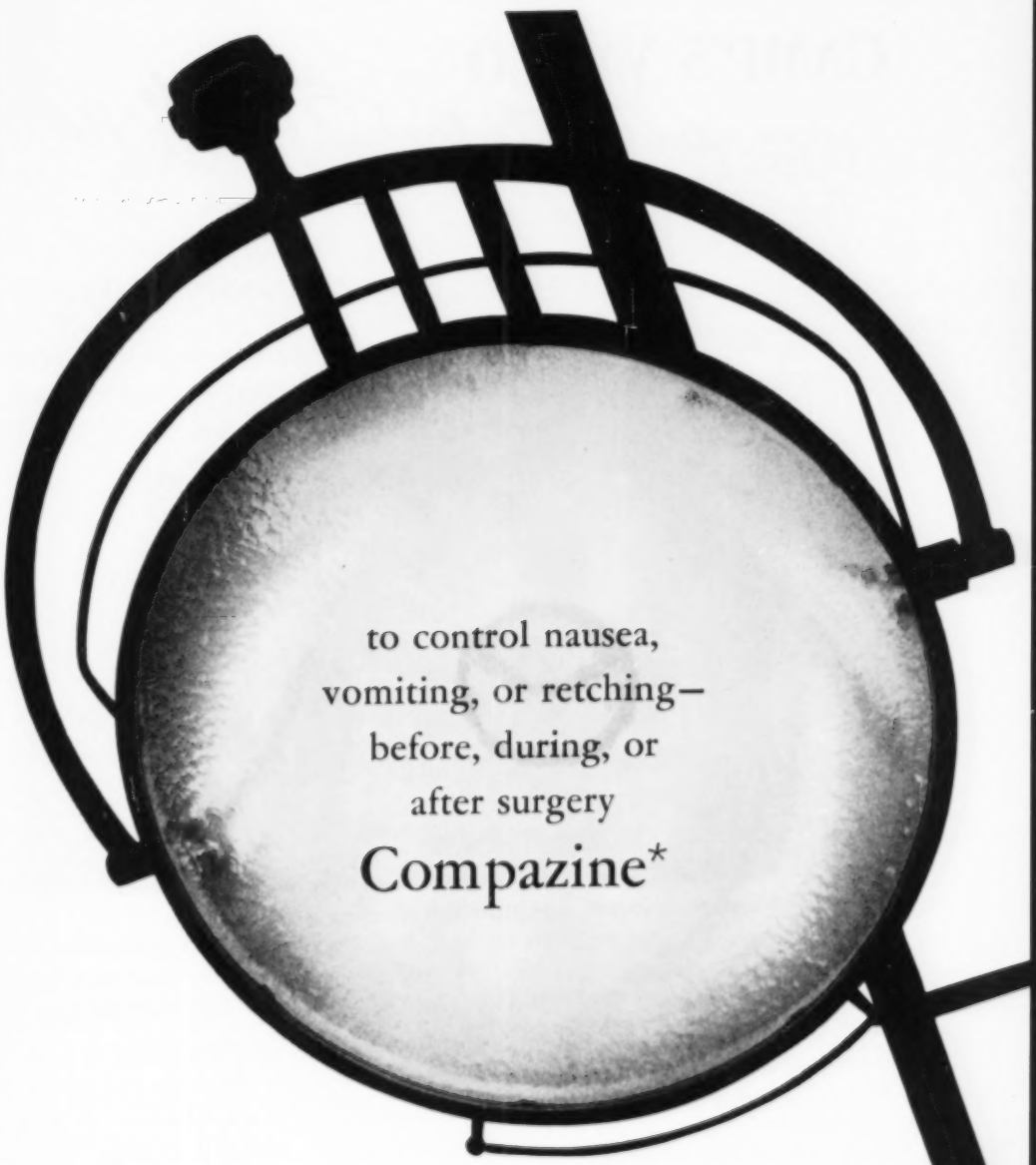

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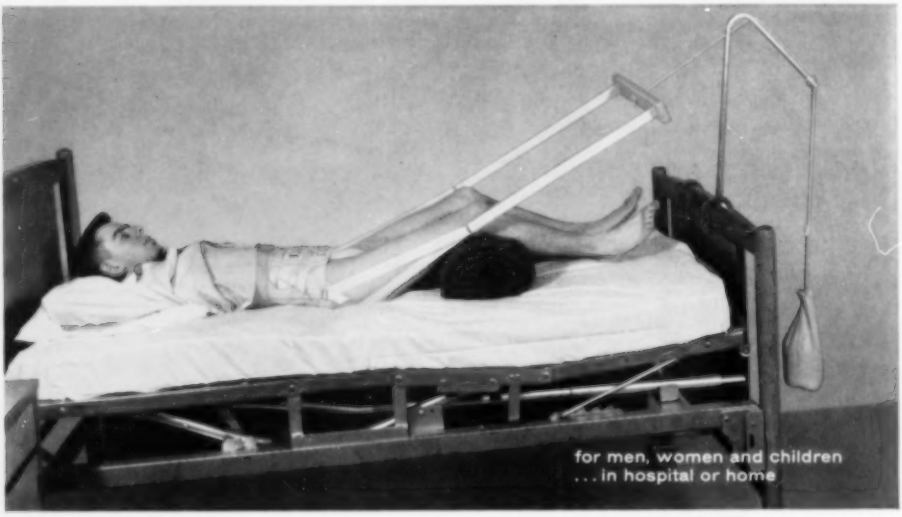

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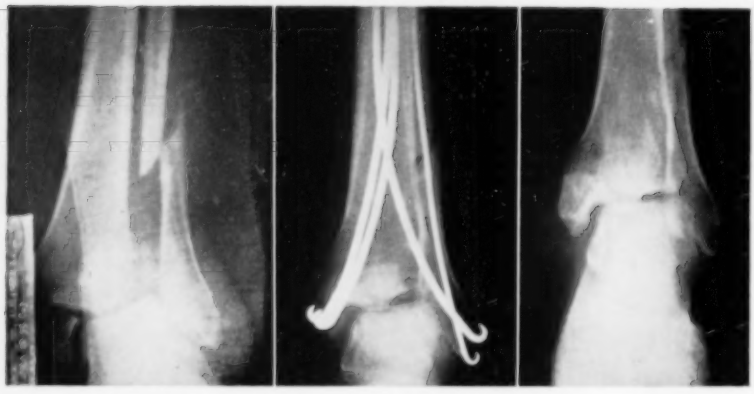


COMPLEX ANKLE FRACTURE

The pins here were straight when driven. Curves were produced by intraosseous pressures to give stable fixation without need for external splinting.

SINGLE PIN

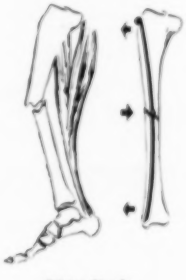
Indicated when both fragments have substantial length.

STRAIGHT PIN: Areas indicated in black.

CURVED PIN: Shafts of humerus, femur and tibia. Resists muscle angulating force by three point pressure.

Humerus Shaft

Femur Shaft



Tibia Shaft

* Rush, Leslie V.: Fracture Problems, Mississippi Doctor, Vol. 36, No. 5:115–118, Oct., 1958.

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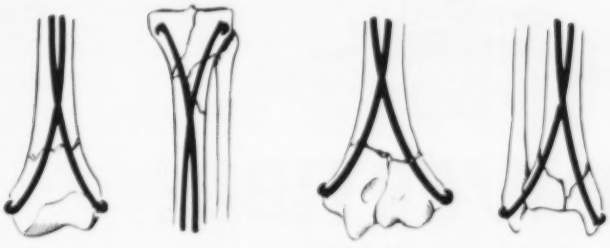
DOUBLE PINS

SIMILAR ANATOMIC AREAS



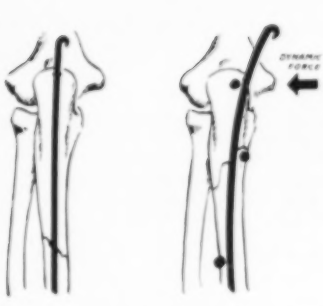
Femur Tibia Elbow Ankle

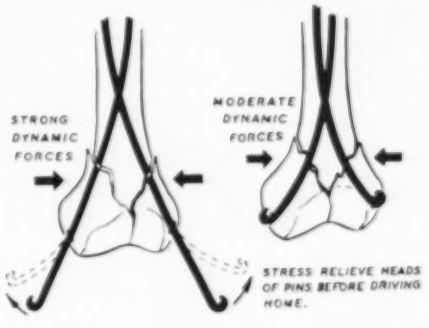
Femur Tibia

COMMINUTED FRACTURES

Similar Problems: Closed pinning best. Relatively good bone length can be maintained.

STRESS RELIEF OF HEADS





Pin inserted through end of bone exerts no dynamic force. Stress relief not necessary.

Pin inserted thrcugh side of bone is forced into curve. Result: Strong dynamic force with three point pressure. Head of pin can sink into bone unless stress relieved.

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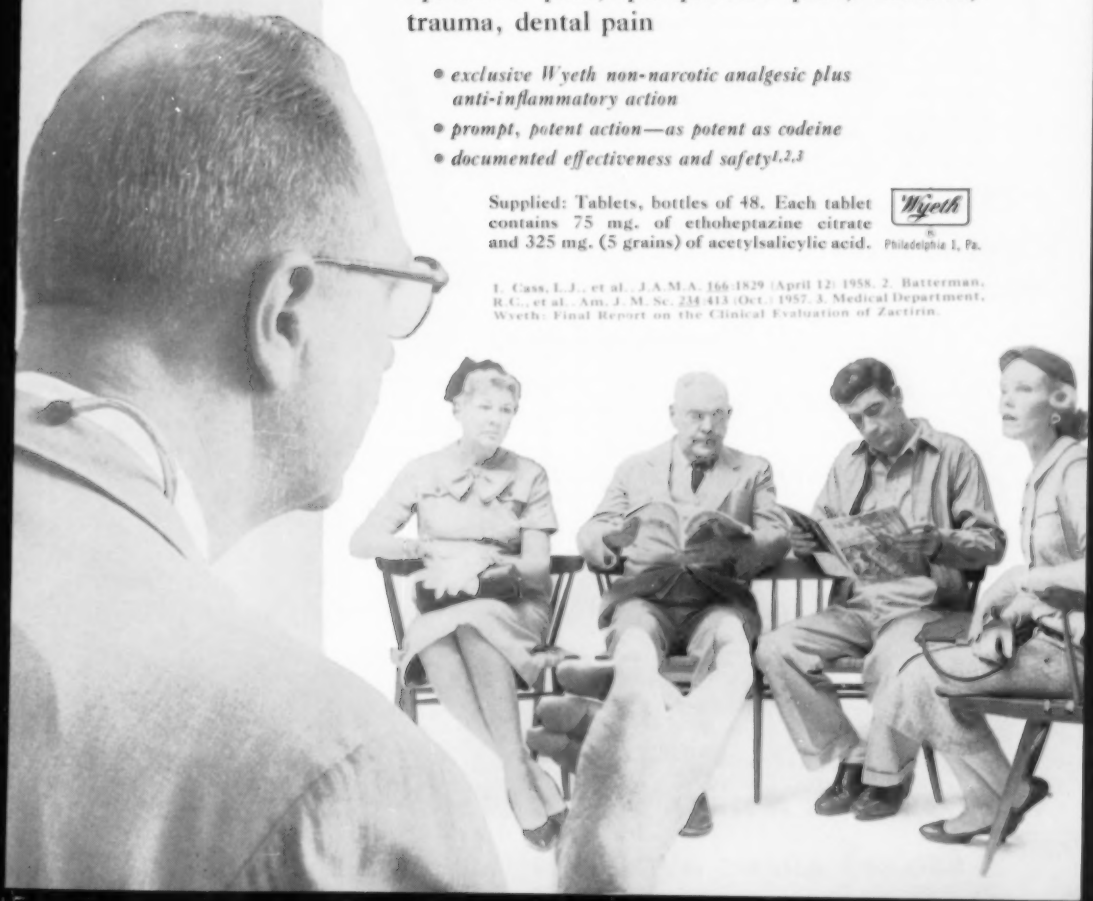
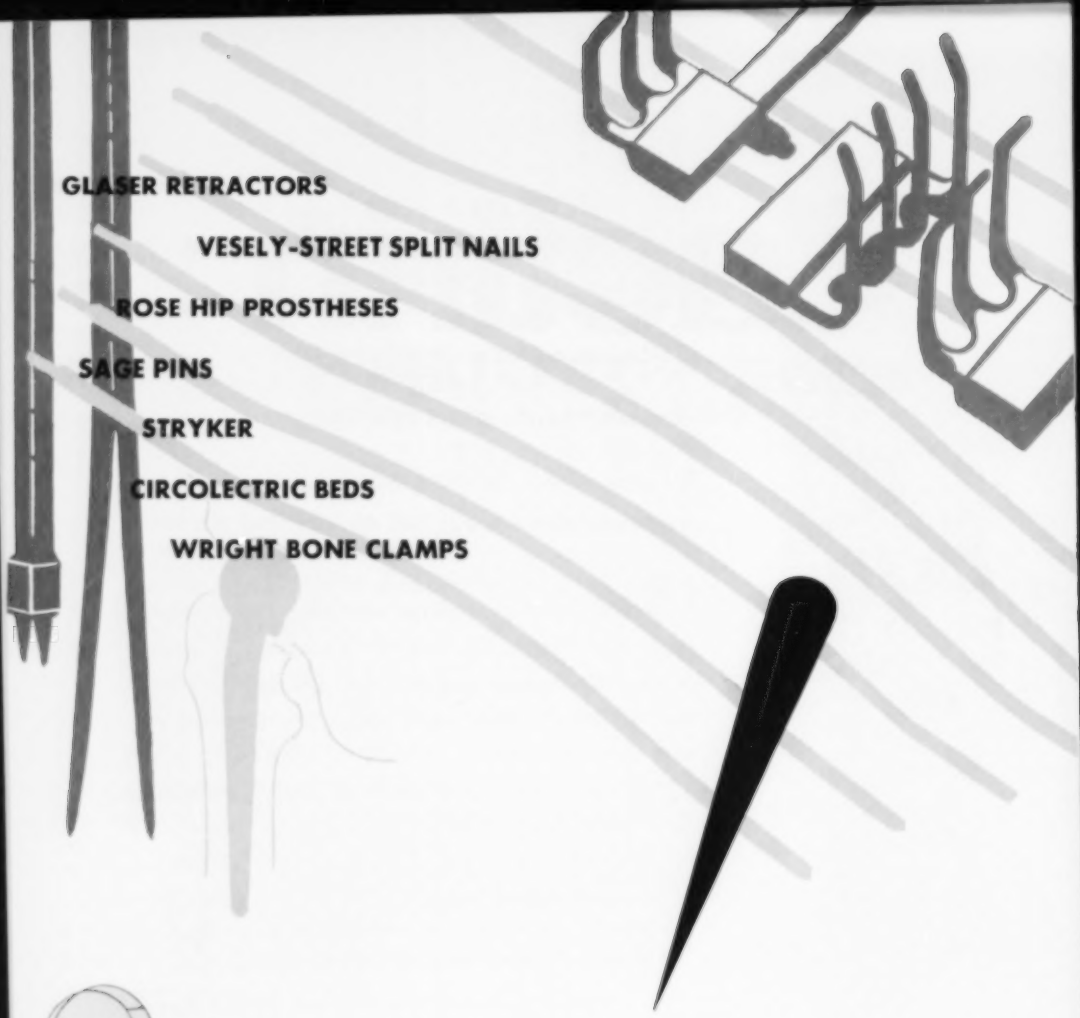
1. Cass, L. J., et al.: J.A.M.A. 166:1829 (April 12) 1958. 2. Batterman, R.C., et al.: Am. J. M. Sc. 234:413 (Oct.) 1957. 3. Medical Department, Wyeth: Final Report on the Clinical Evaluation of Zactirin.





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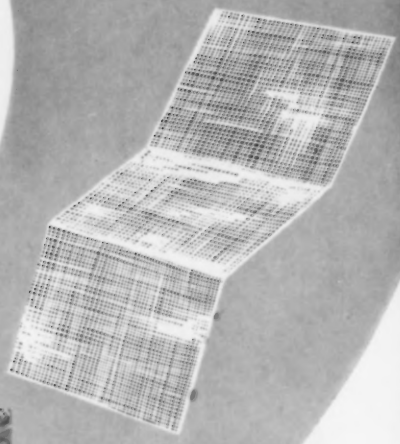

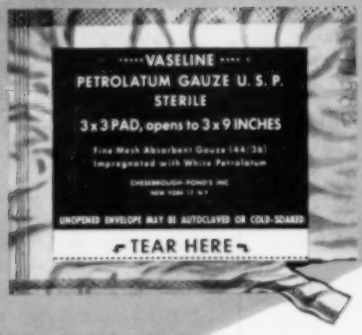
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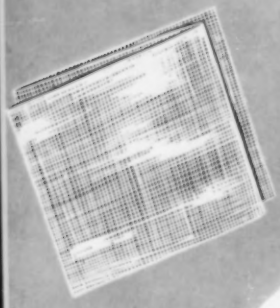

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precautions: The precautions and contraindications that apply to all steroids should be kept in mind when prescribing PARAFON WITH PREDNISOLONE.

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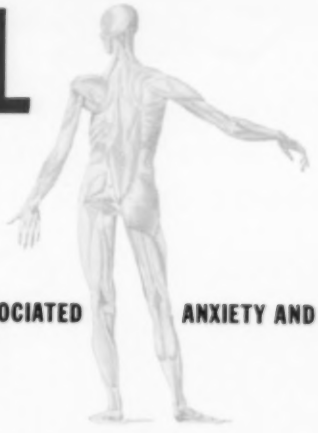

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*Eisenberg, S. H. and Neviaser, J. S.: The use of meprobamate in the treatment of skeletal muscle spasm. Ann. New York Acad. Sc. **67**:853, May 9, 1957.

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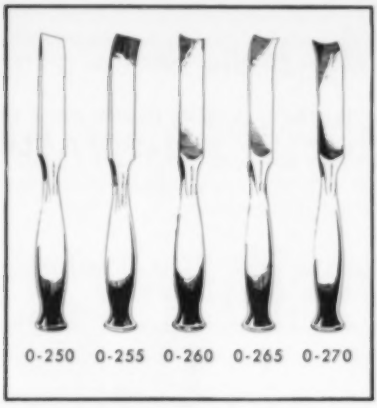

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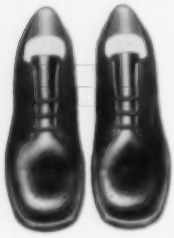

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The Journal of Bone and Joint Surgery

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JANUARY 1959

American Volume
Vol. 41-A

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VOL. 41-A, NO. 1 JANUARY 1959

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(EDITORIALS)

FUSIONS OF THE CERVICAL SPINE

The seven cervical vertebrae with their intervertebral discs and posterior articulations encompass the spinal cord, the nerve roots, and the two vertebral arteries with their associated sympathetic nerves. These structures are compactly associated one with another.

The cervical spine is not only a flexible support between two rigid elements, the head and the thoracic spine, but when normal it also protects the spinal cord and its blood supply, and the vertebral arteries and their associated sympathetic nerves.

The head contains several of the special senses: hearing, sight, smell, and taste. For this reason the head normally moves frequently and often rapidly. The neck is thus subject to constant activity even in people of sedentary habit. If use over time plays a significant role in intervertebral-disc degeneration, it is small wonder that so many people after the third decade of life show cervical-spine wear and tear.

With disc degeneration occurring either gradually without trauma or following acute trauma to the neck, secondary arthritic spurs or bone proliferation eventually appear along the edges of the vertebral bodies and adjacent to the degenerated disc and at sites of isolated degeneration of the posterior articulations. This spur formation can become particularly troublesome in two places.

First, it can be troublesome in the region of an intervertebral foramen for within it a nerve root passes to the brachial plexus and the arm. The edges of the vertebral bodies here form the articulation known as the post-central, uncovertebral, or Luschka's joint. The posterior articulation lies on the other side of the intervertebral foramen and sometimes spurs from this joint protrude into the foramen. These spurs and their overlying soft tissues can compress the nerve root as it passes through the foramen. The nerve root on the other hand often cannot move away from such bone projections because it is rather firmly situated in the bony ring of the intervertebral foramen [4]. These spurs have also been noted to intrude into the path of the vertebral artery [4,5]. Each artery is held rather securely in a connective-tissue canal enclosed within bony rings at each vertebral level from the first to the sixth cervical vertebra. Thus the arteries cannot freely move away from these spurs. Spurs may be particularly troublesome as the vertebral artery passes laterally over the joints between the lateral articular masses of the first and second cervical vertebrae.

Second, osteo-arthritic spurs can give particular trouble when they are present along the posterior margins of the vertebral bodies. Directly behind them in the spinal canal lie the extradural fat and veins, the meninges, and the spinal

cord. The spinal cord is so fixed against the front of the spinal canal by denticulate ligaments that it cannot avoid these bone protuberances on the back of the vertebral bodies if they become sufficiently prominent.

When symptoms and signs are due to compression or irritation of nerve roots, or the vertebral arteries by such bone spurs, treatment by immobilization of the neck with a suitable brace, by continued head-halter traction, and by better posture habits have become time-honored. These measures normally bring relief in from a few days to a few weeks, especially if combined with rest. In other words, if motion at the site of these bone spurs between vertebral bodies ceases, the irritated soft tissues can apparently accommodate to these encroachments.

Notable are the exceptions. Uncommonly, in a patient in the later decades, the pain becomes intractable despite a well planned and carried out program of traction, rest, and adequate external fixation. Constant nagging, local, and often referred pain become incapacitating and almost unbearable. In such a situation spine fusion may be indicated, with or without excision of the posterior articulations, at the intervertebral levels determined to be involved by the offending osteophytes. Such a fusion may be performed by the anterior or posterior approach. By the anterior approach the intervertebral-disc material may be removed and a bone block placed between the vertebral bodies [10]. If immobilization by fusion proves insufficient to stop the nerve-root symptoms such an anterior fusion allows free access posteriorly for subsequent laminectomy and excision of the posterior articulations without loss of stability of the cervical spine. Posteriorly the spinous processes may be incorporated in a fusion mass with bone grafts. The grafts and the posterior spinous processes can be held relatively immobile during fusion by internal fixation afforded by stainless-steel wire when correctly applied to the posterior spinous processes [7]. However, if the posterior arches have been removed, and particularly if prior laminectomy was accompanied by removal of the posterior articulations, then the anterior approach is often the preferable one since it is more difficult to bed the graft posteriorly under such conditions.

Should symptoms of chronic cord attrition be present, characterized by typical neurological signs in the lower extremities, laminectomy with division of denticulate ligaments followed by posterior fusion may be indicated.

Three to five months following extensive laminectomy and excision of posterior articulations, neck pain is not an unusual complication. In such patients there is obvious roentgenographic evidence of distortion of the normal smooth curve of the cervical spine in flexion and extension as seen in lateral roentgenograms made with the patient standing. Cervical-spine fusion appears to be indicated in these instances. The anterior approach often offers less technical difficulty than the posterior approach in such a situation.

A word of caution is due regarding anterior fusion of the cervical spine in the presence of osteoporosis. In such spines it is easy to miss the intervertebral disc and proceed into the body of a vertebra while seeking the disc. Great care must be taken to locate exactly the fusion site. Roentgenographic control at the operating table is essential. This is facilitated with a needle centered in the disc space to be removed. Then one must follow the course of the disc exactly as it passes between the two vertebral bodies that are to be fused together; otherwise, the graft may not be placed in the ideal position between the two bodies. Other precautions regarding anterior cervical-spine fusion have been enumerated [10].

Another word of caution is due regarding the technique of posterior fusion. Subperiosteal exposure of the lamina is adequate when autogenous cancellous iliac-slab grafts are used. Decortication of the lamina is unnecessary and may result in cord damage from the use of the hammer. It is to be scrupulously avoided.

Cervical vertebrae are shaped primarily to impart flexibility to this segment of the spine, a flexibility which is gained at the expense of stability. The highly flexible cervical spine spans the interval between a massive body, the head, and the relatively rigid mass of the chest. Accordingly, the cervical vertebrae are

mechanically vulnerable not only because of their shape but because of their function.

Perry and Nickel [6] point out that "a flail cervical spine is an increasing problem for the orthopaedic surgeon due to the large numbers of persons surviving respiratory paralysis due to poliomyelitis." They noted that when the head extensors are not functioning the neck extensors are usually also paralyzed. If the function of the neck extensors alone is lost, fusion extends from the third cervical to the third thoracic vertebra; whereas if the function of the head extensors is also lost, the fusion is from the occiput to the third thoracic vertebra.

When the head, without warning, is suddenly accelerated or decelerated in relation to the body in snapping injuries, the bony and soft tissues of the cervical spine bear the brunt of such forces without the full help of the muscles. Injuries involving sudden acceleration and deceleration in motoring have become increasingly common in the last forty years for obvious reasons.

Dislocations, fractures, and fracture-dislocations of the cervical vertebrae and disc injuries, whether acute, long-standing, or recurrent, with acute protrusion or subsequent degeneration are especially hazardous because the spinal cord, much of the course of cervical-nerve roots, and vertebral arteries and their accompanying sympathetic nerves are contained within the bone column, injuries to which may be crippling, irreparable, and sometimes fatal. Momentary or persistent diminution in the lumen of the spinal canal of the intervertebral foramina or of the foramina for the vertebral artery may result in compression of any of these structures. This diminution in the diameter of the bone canals in the cervical spine may be continuous or intermittent depending on the nature of the displacement.

A high proportion of cervical-spine injuries result in instability whereby preservation of the lumen of the vertebral canal is no longer assured, regardless of whether or not complete reduction of the fracture-dislocation has been effected by skull traction or any other means. This is inevitable by the nature of the injuries characteristic of those in the cervical spine. Where mechanical instability is present between vertebrae, one may elect to fix and fuse posteriorly the involved laminae and spinous processes. Before finally deciding upon internal fixation and fusion, it is essential that all indications for laminectomy, half or full, be reasonably ruled out in the opinions of those qualified and directly responsible.

Such stabilization procedure may be done early. The bases of the spinous processes of the involved vertebrae are wired together and to those of the normal vertebrae above and below. This affords sound internal fixation while fusion is taking place. The patient can then be ambulatory provided he wears a neck brace until the injured levels of the cervical spine become solidly fused [7]. Such a brace prevents wide ranges of motion thus avoiding erosion of bone by the fixation wire.

After a fairly extensive subluxation or after a dislocation of one vertebral body on another, spontaneous anterior-body fusion and occasionally fusion of the posterior articulations may occur within six to nine months. However, if the patient is treated during this time by external fixation alone, as with a Minerva or Calot jacket, a recurrent subluxation of the cervical spine may gradually appear at the site of injury. This may cause symptoms or be functionally disabling. Therefore, shortly after injury, if one experienced in cervical-spine fusion is available, correction of the post-traumatic deformity may often be effected and secured by internal fixation (a graft held in place by No. 22 stainless-steel wire for instance) and subsequently the patient may be up and about with a light neck brace until fusion is solid. Thus recurrence of deformity in a plaster jacket and the heavy jacket itself are avoided.

When dislocation occurs unilaterally, as in flexion rotatory mechanism, even skull traction may be ineffective in reducing the displacement. Furthermore, the inferior articular process of the superior vertebra at the dislocation site may be compressing a nerve root causing the patient severe pain. When oblique roentgeno-

grams of the spine show this situation to be present, particularly if there is a question of a fracture of the posterior elements of the involved vertebrae, it is the author's firm conviction that open reduction soon after injury is preferable to attempted closed manipulation or extensive trials of heavy traction. Under local anaesthesia the site of dislocation is exposed. The superior part of the more caudad process may be rongeured away under direct vision while the patient can describe any untoward symptoms; the more cephalad dislocated facet is pried back over the more caudad one. If no fracture is present in the posterior arch, this maneuver may be facilitated by firm traction obtained by bone-grasping forceps applied to the spinous processes of the involved vertebrae. Once the reduction is effected the neck can be extended further by gradual elevation and tilting of the cerebellar headrest upon which the patient's head is supported during the operation. Following reduction, the spinous processes of the involved vertebrae can be fixed together by wiring and fused by placing bone over the denuded spinous processes. If a fracture is present the fusion site must of course extend to the first normal posterior arch above and below the fractured arch [7].

When dislocation occurs bilaterally with cord compression or transection, skeletal-tong traction is applied as soon as possible. Subsequently when laminectomy is performed, reduction of the dislocation and fusion are carried out under direct vision, if such reduction and fusion can be achieved without aparent risk of cord compression and if the patient can tolerate the extra surgery. Stability achieved in this way certainly makes convalescence easier. If a transection of the cord is obvious at laminectomy, fusion is indicated to facilitate postoperative care.

If the patient's neurological functions imrove with skull traction without laminectomy or after simple laminectomy even if reduction of a cervical dislocation is not wholly achieved, it would appear best to continue treatment for about three weeks and then fuse the cervical spine, perhaps without further reduction, when it can be done under ideal operative conditions.

Where wide laminectomy has been performed, fusion of the cervical spine is often desirable, if not absolutely necessary, because of pain in the neck, irritation of the spinal cord on motions of the neck, or for obvious instability of the neck shown roentgenographically. In such instances, fusion can be performed by either the anterior or the posterior approach. In cases where fusion of the first and second vertebrae are necessary due to fracture of the odontoid process or because of abnormal mobility between these vertebrae, or in those rare instances where there is abnormal mobility between the skull and the first cervical vertebra, fusion is performed by the posterior approach. In those instances in which there is a fracture of the arch of the first cervical vertebra or where there is instability of the skull on the first cervical vertebra, fusion may be carried from the skull down to the second or third cervical vertebra. Where there is simple instability between the first and second cervical vertebra and the posterior arch of the first cervical vertebra is intact, posterior fusion between the first and second cervical vertebra may be done, after fixing the arches of these vertebrae together by wire in slight extension to prevent redislocation before fusion is complete. Forsyth, Alexander, Davis, and Underdal noted that redislocation had occurred in two of fourteen patients fused for fracture-dislocation of the atlas on the axis when only these two were fused together. Therefore, they have made it a custom to include the third cervical vertebra and use a rib or other rigid cortical-bone graft firmly wired to the posterior arches of the first, second, and third cervical vertebrae, bilaterally, to prevent redislocation between the first and second cervical vertebrae after fusion. As noted previously, these operations by the posterior route can be performed under local anasethesia and thus one avoids intubation problems and the loss of voluntary cervical-muscle control. On the other hand, some patients cannot tolerate an operation of this magnitude under local anaesthesia.

In those instances where extensive laminectomy has been performed or where there are fractured posterior-arch elements and fusion is desired somewhere be-

tween the second cervical and first thoracic vertebra, the anterior cervical approach may be used. However, the anterior cervical approach does not lend itself to local anaesthesia. Therefore where there is a desire for the operator to know the reaction of the patient at different stages of the operative procedure, it is best that the operation be performed through the posterior approach where local anaesthesia can be used.

If a section of the cervical spine, devoid of posterior arches from some previous laminectomy, is to be fused from the posterior approach, bone can be laid down over the exposed posterior articulations on each side of the spinal canal and fixed in place by running No. 22 gauge stainless-steel wire through drill holes in the inferior articular processes of each of the vertebrae to be fused on each side of the spine. These wires enter the drill holes superiorly and come out of the joint inferiorly at each vertebral level. These various loops are then closed and tightened in turn over a strut of bone lying over the joints on each side [11]. In all instances of posterior cervical-spine fusion it seems well, if possible, to stabilize the grafts and the spine with No. 22 stainless-steel wire, particularly if a dislocation has been reduced. Thus position will not be lost, less bulky external fixation will be necessary postoperatively, and fusion will occur more quickly because of the immobilization that is possible when wire fixation is applied efficiently.

Several points of caution ought to be mentioned in relation to the procedure of fusing the cervical spine. If the fusion is to be performed under general anaesthesia for an unstable fracture or dislocation or for severe osteo-arthritis, it is mandatory that during intubation neither flexion nor extension of the neck be permitted. Nasal intubation is, therefore, advised. Whenever there is doubt about the stability of the spine and when for this reason the patient's own muscle control of his neck is desirable during cervical-spine fusion, it would appear best, if the patient can tolerate it, to do the fusion posteriorly under local anaesthesia. For instance, local anaesthesia is advised when reduction of bilateral complete anterior dislocation and subsequent spine fusion is to be done.

Fusion is also indicated in treating tuberculosis, and also in certain neoplasms of the cervical spine especially where stability is threatened.

The spontaneous cervical dislocations, often multiple, which are uncommonly found in rheumatoid arthritis may present a difficult problem in treatment. It would seem that for the present each has to be treated on its own merits.

SUMMARY

Fusion of the cervical spine may be done by the anterior approach from the level between the second and third cervical vertebra down through the seventh cervical and first thoracic vertebra. Fusion through the posterior approach may be performed all the way from the skull to the thoracic vertebrae including all or any combination of cervical vertebrae that may be desired. It appears that there are two important indications for fusing the cervical spine: to prevent mechanical irritation of important neural and vascular tissue at sites of bony spur formation between two vertebrae, and to maintain the normal dimensions of the various bone canals in the cervical spine when instability between cervical vertebrae tends to constrict these canals.

The timing, the anaesthesia, and the approach should be considered carefully prior to surgery. Roentgenographic control in the operating room is often essential and always desirable. When dealing with the cervical spine one must remember that the function of the spinal cord, the nerve roots, and the vertebral arteries, with their accompanying sympathetic nerves, is the most important consideration. Surgery on the bone structures of the cervical spine must be designed to protect or improve the function of these enclosed soft tissues.

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ON SPINAL-CORD INJURIES

As yet there exists no unanimity of opinion relative to the treatment of vertebral injuries; this is particularly true in cases where the spinal cord is involved. Neurosurgeons of comparable experience and judgment, and of unquestioned integrity, frequently hold completely divergent views on various phases of this problem. Men who are acknowledged experts in the field of spinal and spinal-cord surgery differ markedly in their opinions on the management of spinal injuries. Nevertheless, I will dare to make certain dogmatic statements concerning these injuries, and will then qualify and discuss them in more detail.

1. If paralysis occurs immediately, and is complete for twenty-four hours following injury, it will be permanent; no form of treatment directed toward the spinal cord itself will aid in its amelioration. (This does not apply to lesions of the cauda equina.)

2. In any closed type of fracture-dislocation of the cervical spine, the immediate application of skeletal traction, first described by Crutchfield, should be undertaken as soon as possible.

3. If, following the reduction or partial reduction of a fracture-dislocation of the cervical spine, paralysis is absent and instability persists, Rogers' rule that treatment should be aimed at preventing late or further cord damage by stabilizing the cervical spine through internal fixation and fusion is, I believe, a sound rule to follow.

4. In the syndrome of acute central cervical-cord injury, as described by Schneider [9], in which there is no evidence of fracture-dislocation, yet paralysis of the upper extremities is present in the presence of function in the lower extremities, laminectomy is contra-indicated.

5. In those rare cases where the neurological lesion is progressive, immediate laminectomy should be carried out, if a disturbance in the alignment of the vertebral bodies cannot be rapidly corrected by skeletal traction.

Before the preceding statements are discussed in greater detail, it might be well to say a word about the symptoms and signs which help to locate the vertebrae involved in a fracture-dislocation before roentgenograms are made. A severe, continuous pain which radiates from the neck into both occipital regions suggests fracture-dislocation of the atlas on the axis. If roentgenograms have been made and have been interpreted as normal, others should be made if the pain continues for a period of days, since an atlanto-axial dislocation is sometimes slowly progressive and may be overlooked at an early stage, even by experts.

When paralysis results from a fracture-dislocation of the sixth on the seventh cervical vertebra, the fifth and sixth cervical-cord segments, which innervate the biceps muscles, are usually spared. The position of the patient in such cases is ordinarily a characteristic one; the arms are in a flexed position across the chest and the motionless hands are half closed. If the fracture-dislocation is of the fifth on the sixth cervical vertebra, the arms may be held at right angles to the long axis of the body, the forearms being moderately flexed, and the hands lying at the level of the head. If the fracture-dislocation is at the fourth or fifth cervical vertebra and paralysis occurs, the arms will lie motionless at the patient's sides. A fracture-dislocation of the third or fourth cervical vertebra, involving paralysis, is ordinarily fatal, although I have seen one patient with this injury who survived.

The location of a fractured vertebra in the thoracic region is usually not difficult to determine when paralysis is present. The locus is ordinarily a vertebra or two above the cord segment at the uppermost level of anaesthesia. It should be remembered that the fifth thoracic segment encompasses the nipples; and the tenth, the umbilicus.

In fractures at the twelfth thoracic or first lumbar vertebral level, where damage to the conus medullaris results, there is loss of sphincter control and the ankle reflexes are usually absent. No anaesthesia may be demonstrable over the anterior surface of the body in such cases, but one should never fail to examine the saddle area where anaesthesia will be found. In any back injury which causes complete motor and sensory paralysis of the legs but when normal control of the anal and vesicle sphincters remains, the diagnosis is inevitably one of hysteria.

For anatomical reasons, the damage to nervous tissue resulting from spinal injury varies in the cervical, thoracic, and lumbar regions. Fracture-dislocation is most likely to occur in the more mobile portions of the spine, or when a mobile portion of the spine adjoins a more stable one. The thoracic spine is comparatively well fixed by the rib cage, and is not commonly injured except for the twelfth thoracic vertebra which, incidentally, is not similarly fixed. In the thoracic region, the narrowness of the canal in proportion to the size of the cord is more likely to give rise to spinal-cord damage than in the cervical and lumbar spine where the canal is wider. The experienced neurosurgeon knows that because of the narrowness of the thoracic canal, there are few operations as difficult as the removal of a ruptured disc from the thoracic area; and, if the disc should be calcified, the difficulties are compounded. (I have never seen recovery take place when complete paralysis has followed non-operative trauma to the thoracic spine.)

The spinal cord ends, as a rule, at the level of the first lumbar vertebra as the conus medullaris. Injuries to the lumbar spine below this vertebra consequently have a far better prognosis. The cauda equina, whose components have the structure and mobility of peripheral nerves, is less vulnerable to trauma, whether caused by fracture or missile, than the more fixed and softer conus. I have seen a complete lateral dislocation of the body of the third on the fourth lumbar vertebra which resulted in almost no weakness of the lower extremities and which left the sphincters intact.

When the cervical spine is extended, the articular processes become locked in their normal position making the spine extremely stable and resistant to dislocation. In cases of acute flexion of the cervical spine, on the other hand, the vertebrae are particularly prone to dislocation by a downward compressing force,

and the overriding of the superior vertebra will be marked if the intervertebral disc is torn from one of the cartilaginous plates. When the intervertebral disc is avulsed and the superior vertebra slips far forward on the one below, the ligamentous and capsular structures surrounding the articular processes will be torn as well, so that the vertebrae involved can be widely separated by traction and reduction facilitated. Conversely, when reduction is easily accomplished, redislocation is most likely to occur. As Badgley has pointed out, it is in these cases with roentgenographic evidence of instability that fusion should be performed. It is in the minor types of displacement, where the disc is not avulsed, that reposition may be found to be quite difficult. Considerable force is needed to disengage abnormally locked articular processes when the ligamentous vertebral connections have not been damaged. It is in such cases, at times, that open reduction with skeletal traction applied must be employed so that the articular processes can be exposed, and reduction, under direct vision, accomplished. It would seem only logical to perform posterior fusion at the same time, provided an extensive dural exposure is not present.

It is now generally agreed that patients suffering from fracture-dislocation of the cervical spine, whether the spinal cord is or is not involved, should be placed immediately in skeletal traction. Crutchfield, whose method revolutionized the treatment of fracture-dislocation of the cervical spine, has advised that not more than thirty-five pounds of weight be used and that this amount be reduced to from five to seven pounds as soon as reduction has been completed in order to minimize overstretching the ligamentous structures, which, in his opinion, tends to increase the possibility of subsequent instability of the spine. He advised that traction be maintained for six weeks in cases of fracture-dislocations of the lower cervical vertebrae and three months in cases of dislocation of the atlas on the axis. He felt that if this procedure was properly carried out, fusion would rarely be necessary. With this view, I am not wholly in accord. Internal fixation by wiring the atlas to the axis, while skeletal traction is applied, is not an unduly dangerous procedure, and a posterior bone fusion carried out at the same time guards against redislocation and markedly shortens the period of immobilization. Following Badgley's advice, Yglesias and I performed posterior fusion for an atlanto-axial dislocation in 1934, and many cervical dislocations have since been fused successfully at the University Hospital without increasing the neurological defect and without fatality.

Several recently recognized syndromes associated with spinal injuries are of interest. The so-called tear-drop fracture-dislocation of the cervical bodies, described by Schneider [5] (also described by others as the bursting fracture of the vertebral body), results from an acute flexion injury in association with severe longitudinal compression. The result is a forward extrusion of a portion of the anterior part of the body along with a protrusion of the postero-inferior part of the body into the vertebral canal. The cord may be completely crushed against the lamina but if the denticulate ligaments hold, attaching the cord to the dura, the trauma may be dissipated into the anterior part of the spinal cord, sparing the posterior columns. The result is that below the lesion there is paralysis with loss of the sense of pain and temperature, but with preservation of the sensations of touch, motion, and position. That the denticulate ligaments may aid in preventing the cord from being crushed against the laminae is most probable, for I have never seen traumatic rupture of the denticulate ligaments except when complete pulping of the spinal cord has occurred.

The tear-drop or bursting fractures should be treated immediately by cervical traction. If some cord function has been preserved and the neurological signs do not improve within a few days, laminectomy performed with the patient in traction is probably advisable. Although the chances are that the damage to the cord occurred immediately at the time of injury, there is always the possibility of a protruding disc which can be removed. Under these circumstances it is advisable to

explore the cord by laminectomy, cutting the denticulate ligaments to decompress the cord thoroughly. If recovery takes place after this type of fracture there is a tendency for symptoms to recur later and, for this reason, it is advisable to perform a fusion of the involved vertebral body to the vertebrae above and below through an anterolateral approach.

In 1951, Taylor reported the case of a patient who showed no evidence of fracture-dislocation of the cervical spine by roentgenogram but whose spinal cord had been severely damaged. He attributed this to compression of the spinal cord between a bone spur, anteriorly, and the inward bulging ligamentum flavum, posteriorly. He demonstrated this mechanism, by myelography, in cadavera.

In cadavera of elderly people, in which hypertrophic bone spurring was known to be present, hyperextension produced encroachment on the spinal canal, both anteriorly and posteriorly. Schneider [5] has collected a series of cases of what he has termed "acute central cervical spinal cord injury." He has demonstrated by mechanical means, and by postmortem examination, that the effect on the spinal cord as described by Taylor is to concentrate the injuring force in the central part of the cord, whether or not it results in concussion, oedema, or necrosis. Since the outer portion of the cord is spared to some extent, the nerve fibers to the lower extremities which lie most superficially in the pyramidal tracts will not be markedly damaged; while the central portion of the spinal cord, which includes the anterior horn cells and the most medial portion of the pyramidal tracts, absorbs the main impact, resulting in paralysis of the upper extremities. This syndrome is being recognized more and more frequently in older persons who have suffered a hyperextension injury of the cervical spine but who show no evidence of fracture-dislocation. The syndrome is characterized by paralysis of the hands, weakness of the arms, and sphincter disturbances, but the patient still has some use of his lower extremities. The prognosis depends upon whether or not the concentration of the force centrally in the cord has resulted in true structural damage or merely concussion or oedema. In the absence of a manometric block, which might indicate an extruded intervertebral disc, surgery is contra-indicated in patients with this syndrome. Personally I can see no reason for immobilizing patients in this older age group by traction. The prognosis is sometimes surprisingly good.

The most controversial decision relating to spinal-cord injuries is this: should laminectomy be performed? If the paralysis is immediate, complete, and lasts for a period of twenty-four hours, function of the spinal cord will not return; and if the vertebral malalignment in the cervical region is corrected nothing can be accomplished by open operation, whether or not a spinal manometric block is present. If pressure is brought to bear on the surgeon by the patient or his relatives for the performance of a laminectomy, I do not see how the surgeon can refuse to do the operation although he should stress the fact that reduction of the dislocation has achieved all that a laminectomy could accomplish. A number of patients have remarked to me, after enduring long periods of paralysis, that they wish that somebody had looked at their spinal cords.

It is in the incomplete lesions of the cervical spinal cord that the question of laminectomy is so highly debatable. If the lesion is incomplete and realignment of the vertebral column has been established, laminectomy is advisable if the paralysis does not improve; but the operation should be performed only when the general condition of the patient has become stabilized. Such an operative procedure must be carried out while the patient is in traction, and by sharp dissection. This is one operation in which the gloved finger should palpate the depths of the incision, probing for laminar defects and exposed dura during the process of exposure in order to prevent further injury to the already severely compromised spinal cord. Fatality in such operations today is almost negligible. There are, however, two disadvantages in operating upon incomplete lesions of the spinal cord. The first is that the unskilled surgeon, in exposing a displaced and compromised spinal cord, may eliminate any chance for future improvement in function

by a false move. The second is that laminectomy further increases the instability of the cervical spine, but anterior fusion can always be carried out later through a lateral approach to the bodies of the vertebrae.

Some ingenious experiments were recently carried out by Tarlov in which paralysis was produced in dogs by inflating balloons intraspinally and then simulating decompressive laminectomy by deflating the balloons. When large compressive forces were used, he found that recovery could take place in the spinal cord if the compression was released within three minutes after paralysis was produced. With minimal spinal compressive forces, recovery occurred after periods of compression as long as two hours. Tarlov urges early decompression in fracture-dislocations which are accompanied by spinal-cord paralysis—mainly, it would seem—on the basis of his laboratory research. This appears illogical to me since experiments on the spinal cord of the dog cannot be applied to man; the compressing force of a balloon cannot be compared with that of bone fragments; a decompressive laminectomy cannot be compared with the deflation of a balloon since in the former procedure it is often very difficult to free the anterior surface of the spinal cord from the posteriorly projecting, kyphotic fragmented body even when the denticulate ligaments are sectioned. Finally, how would it be feasible to decompress a spinal cord even two hours after a fracture-dislocation has occurred; and what would be the mortality rate?

An interesting and important sidelight of Tarlov's study is the demonstration that "Great compressive forces applied to the cauda equina for as long as five hours, and probably much longer, are compatible with full functional recovery after their release". This statement coincides with the opinion of most neurosurgeons, particularly those who have seen war service; but, as far as I am aware, this experimental study represents the first real documentation of neurosurgical clinical impression.

The evidence for the greater resistance to trauma of the cauda equina over the spinal cord leads nicely to a discussion of laminectomy in fractures of the twelfth thoracic and all of the lumbar vertebrae. When the conus medullaris is damaged as a result of acute bone compression, as evinced by complete saddle anaesthesia, loss of sphincter control, and absent ankle reflexes, recovery of the conus simply does not take place. The added tragedy of permanent impotence makes one wonder why nature should have placed the conus near so vulnerable a spot as the thoracolumbar junction. In fractures of the spine in this region, a pure conus lesion is a rarity, since paralysis of the lower extremities is the usual result. Such paralysis is ordinarily not caused by spinal-cord involvement, but rather by damage to the cauda equina. Even were the axons of the motor components of the latter crushed, regeneration could take place if the fibrous epineurium of the fasciculi were still intact. This is not true of the sensory components, since their ganglion cells lie outside the spinal canal, and regeneration cannot take place where there is a lesion between the ganglion cells and the spinal cord. Nevertheless, in view of the resistance of the cauda equina to trauma, the great majority of neurosurgeons would want the fracture site explored with the greater expectancy that the patient would be able to walk again, unless a technically excellent lumbar myelogram showed no evidence of abnormal encroachment on the spinal canal. The problem of when to operate arises once more. If surgery has been decided upon, it is probably safe to say again that the operation should be performed after the patient has recovered from shock and his pulse and blood pressure have become well stabilized.

In fracture-dislocation of the thoracic spine involving complete paralysis, surgery is of no avail except for psychological reasons. If the paralysis is incomplete and improvement in function is not progressive, laminectomy should be carried out, particularly where a manometric block is present. I am certain that I have seen recovery hastened in such cases by laminectomy.

There is one almost absolute indication for thoracic laminectomy in the pres-

ence of complete paralysis: when a roentgenogram shows the deformity to be so severe that eventual weight-bearing will be impossible, or when the roentgenogram indicates that there is a traumatic gibbus so extreme that decubitus formation directly over it seems inevitable, surgery is directly called for. In such cases the dura should be exposed and reduction accomplished on the operating table. under direct vision, and fusion performed. In the presence of marked anterior wedging in the lumbar region where the fracture has involved the articular processes, it is sometimes necessary to perform open reduction after exposure of the dura, even in the absence of paralysis.

A defeatest attitude still clings to the operative approach to spinal-cord injuries. This is owing, in part, to the fact that patients affected by immediately complete paralysis rarely recover function, and also because one can seldom be certain that improvement has resulted from a particular method of treatment. Every case is an individual one and calls for cooperation among the orthopaedist, the neurosurgeon, the urologist, and, later, the physiotherapist. Improvement in results will come only through further cooperation coupled with research in fields as far removed from the practice of medicine as physics, chemistry, and mechanical engineering.

Edgar A. Kahn, M.D.

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INJURIES TO THE CERVICAL CORD

Fundamental Factors in Treatment and Rehabilitation

When the cervical cord is traumatized, the injury is invariably fatal if contusion above the mid-cervical level is severe or if ensuing oedema or hemorrhage extends above the fifth cervical vertebra. The phrenic motor-nerve cells lie in the second, third, and fourth cervical segments; hence, death from respiratory failure results from paralysis of the diaphragm and intercostal muscles. Even if the diaphragm is only partially paralyzed, the patient becomes confused and gradually sinks into coma, unless cerebral anoxia is treated effectively. On the other hand, when the four upper cervical vertebrae remain intact and the corresponding por-

tion of the spinal cord is not damaged by ascending hemorrhage or swelling, the younger patients are likely to survive, provided there are no serious cerebral or other complicating injuries. In a series of thirty-two traumatic quadriplegics ranging in age from thirteen to eighty-two admitted to the neurosurgical service of the Massachusetts General Hospital in the period from 1946 to 1958, twenty-four have survived.

Experience at military and civilian hospitals since World War II has been in striking contrast to the statistics of the former war with Germany, when prolonged survival was rare even among the paraplegics. The appalling mortality prior to the early forties was primarily due to neglect of hypoxia, ignorance of nutritional requirements necessary for tissue healing, and inability to prevent or treat advancing bedsores and urinary complications. In addition, effective physical therapy, as well as psychological and physical rehabilitation of the chronically paralyzed individual, were virtually unknown. As a result the great majority of these unfortunate individuals lay in bed until they succumbed to chronic infection and amyloidosis. The purpose of this editorial is to point out how much can be done to protect the quadriplegic in the critical early stage of his injury and then to rehabilitate him for a relatively useful survival in the community.

The first essential is to protect all individuals with injuries to the cervical vertebrae against increasing damage to the spinal cord, which may not at first be irrevocably contused or even seriously damaged. This requires prompt recognition of a fracture or dislocation. Diagnosis of cord injury is of course obvious in the conscious paralyzed victim of an accident. It is not so easy to detect this in the patient who is unconscious from added cerebral concussion. The examining physician must always bear in mind that coincidental injury to the cervical spine may also be present and make sure that intercostal respiratory movements have not been lost. He should also think of a possible vertebral injury without paralysis in any patient who complains of pain in the occiput, neck, or arms, because careless transport may lead to unnecessary and irreparable damage to the cord. The cervical cord, so vulnerable to pressure, is most often damaged by flexion, but hyperextension of the neck is also a possible mechanism from posterior compression by the fractured laminae or interlaminar yellow ligaments. Therefore during transportation the head and cervical spine must be stabilized with extreme care in the longitudinal plane of the body with the chin up and only a small pad under the neck to maintain the normal lordotic curve.

On arrival in the hospital emergency ward complete stability may be maintained by the application of a turnbuckle extension collar of the type sold by surgical supply houses. Roentgenograms in the anteroposterior and lateral position, together with open-mouth views of the odontoid process, can be made without removing this protective device. The next step is to apply cranial traction by means of Barton, Crutchfield, or one of the other types of tongs. This should be done on every quadriplegic patient, even if no fracture or dislocation is visible in the roentgenograms. The patient is then transferred from stretcher to bed with initial traction of ten to fifteen pounds applied with the neck in neutral position by means of a pulley at the head of the bed. Heavier traction will be required if there is an additional dislocation to reduce. Once in traction the patient is safe for turning, which must be done hourly around the clock to prevent bedsores. An inlying Foley catheter (not larger than No. 16) is inserted to prevent distension of the bladder. This step is of primary importance, not only to promote early recovery of urinary control, but to permit maximal descent of the diaphragm.

There are a number of other steps which must be taken at this time to prevent critical respiratory embarrassment. These can best be started in an operating or recovery room where apparatus for treatment of anoxia is available and where the patient can be closely observed until the vital signs are stable and the danger of respiratory failure is past. The attending surgeon must realize that vital capacity in the early stage of contusion and spinal shock is usually reduced to a seriously

low level of between 500 and 1000 cubic centimeters. Deducting 200 cubic centimeters of air which fills the air passages (tidal volume), this means a critically low volume of respiratory exchange. Oxygen administration fulfills a dual purpose—increasing the amount of oxygen that reaches the alveoli and diminishing the nitrogen in solution in the blood. There are two other methods of increasing a dangerously low vital capacity: (1) tracheostomy, which bypasses the dead space in the larynx and nasopharynx and also permits more effective clearing of the airway by the aspiration of secretions and (2) application of a snug swathe to the lower ribs, which reduces the elastic expansion of the ribs at the end of expiration. This has been found to increase vital capacity by as much as 100 cubic centimeters. During the early stage of spinal shock, when all reflex activity is abolished in smooth as well as skeletal muscle, nitrogen accumulates in the paralyzed intestines. This leads to abdominal distension and further handicaps diaphragmatic respiration. If the nitrogen content of the inspired air is reduced, the nitrogen tension in the blood will be likewise diminished and more of the gas will be removed from the distended intestine. At the same time, in order to reduce the formation of gas in the intestines, only intravenous fluids should be given for the first few days until the return of audible peristalsis denotes that the stage of paralytic ileus is past.

The most difficult decisions to make after an acute paralyzing injury to the cervical cord concern the questions of whether or not to operate and when the operation should be performed. It is generally conceded that surgical intervention is advisable to reduce obvious dislocation, if this cannot be corrected by traction, and whenever paralysis continues to increase; also when lumbar puncture demonstrates a complete dynamic block on jugular compression. Experience in World War II and in Korea has shown that, in addition to the primary débridement and closure of external missile wounds, it is also advisable to explore the site of the spinal lesion as soon as the patient's condition permits. Missile tracts between trachea or esophagus and subarachnoid space may lead to meningitis; furthermore, small spicules of bone, invisible in the roentgenogram, may be driven into the spinal cord.

When to operate on these patients is always a difficult decision, as early anaesthesia and manipulation are so likely to lead to fatal cerebral anoxia. Surgical decompression, even at the earliest possible moment, cannot restore function if the cord has been severely contused and the results of such surgery are generally unimpressive. If the contusion is not irrecoverable and there is no evidence of residual compression, spinal conduction will soon start to recover whether decompression is done or not. Weighing these factors, it is evident that surgical intervention is far more likely to do harm than good if undertaken too early in the period of threatening respiratory failure or in the absence of positive evidence of continued compression by vertebral fracture or dislocation, prolapse of disc tissue, or swelling of the cord from hemorrhage or oedema. In the absence of an open wound, my own inclination is to delay a few days until the patient is recovering from spinal shock, with a blood pressure that can be maintained above 100 and a vital capacity of over 1000 cubic centimeters.

When operation is undertaken, it should be performed under pentothal and nitrous oxide in addition to local infiltration anaesthesia, with traction of twenty pounds to the skull. It requires an expert anaesthetist to pass an intratracheal catheter through the larynx without hyperextending the neck and to administer a high volume of oxygen with assisted respiration. In addition to carrying out a decompressive laminectomy and removing loose fragments of bone, rents in the dura should be patched, the dislocation reduced, and some form of internal vertebral stabilization performed, when this is feasible. While complete spinal recovery rarely results, when it would not have taken place spontaneously, experience has shown that operation performed after the first critical days is relatively safe and has the following advantages:

1. Protection in penetrating wounds against meningitis resulting from septic fistulae;

2. Reduction of radicular pain from compression of emerging roots of the brachial plexus;

3. Recovery of compressed plexus roots, above the level of spinal transection. This may lead to useful recovery of paralyzed brachial muscles. For instance, a patient with arms paralyzed except for intact deltoid, biceps, and brachioradialis muscles (from fifth and sixth cervical-nerve roots) may regain useful power in his triceps if function recovers in the seventh cervical root. With this there is often some return of muscular activity in the forearm as well.

In addition, the patient whose fractured vertebrae have been stabilized can be got up out of bed in a supporting collar at a much earlier date. This is a tremendous asset in reducing demineralization of the skeleton and the formation of urinary calculi, as well as in the prevention of bedsores, maintenance of a satisfactory caloric-nitrogen balance, and the all-important factor of the patient's morale and will to recover. With the patient able to get out of bed, physical therapy can be carried out more effectively and rehabilitation started at a much earlier date.

It is difficult to compress the important fundamentals of treating injuries to the cervical portion of the spinal cord into an editorial of readable length. In writing this I have attempted to point out the essential factors that make the difference between survival and death or relatively brief survival as a hopeless cripple. The neurosurgeon must bear the responsibility with the orthopaedist during the early critical stage in which the conducting sensory-motor and autonomic axons of the spinal cord may either survive to recover function or degenerate irrevocably. The fate of these sensitive structures will become apparent during the first month. This is a particularly vulnerable period in which the assistance of all the hospital services must be called upon. The most urgent requirement is expert nursing to prevent bedsores and hypostatic pneumonia, as well as to ensure an adequate caloric-protein-vitamin intake to avoid hypoproteinaemia and malnutrition. Those of us who served in neurosurgical centers in the last two wars will never forget the degree of emaciation with loss of will to live, or the terrible bedsores and their failure to heal seen in the survivors of spinal injuries from distant outposts where early adequate care was impossible; or, conversely, the amazing improvement that took place when anaemia, low serum protein, malnutrition, and avitaminosis had been corrected.

There is no longer any justification for the physician confronted with one of these terrible injuries to adopt a defeatist attitude. Above all, he should encourage the patient and his family not to give up hope, bearing in mind that many of these initially quadriplegic victims will regain a useful degree of sensory-motor function in their lower as well as upper extremities. This has been the case in seventeen of the forty-three patients whom my associates and I have treated during the last twenty-five years, with virtually complete recovery in six.

The emotional impact of sudden paralysis is so shattering that the patient can easily lose all desire to cooperate and get well. It takes the expert help of a psychiatrist as well as the collaboration of the social worker, minister, and the patient's own family to combat his sense of helplessness and depression. Once the patient has gained the will to survive and to overcome his handicaps, near miracles can be accomplished. Tidal drainage and effective bowel training can restore satisfactory automatic evacuation through spinal reflex mechanisms. Only a minority need to remain on a permanent catheter regimen. Bedsores, if they develop, can be closed by plastic surgery, and their tendency to recur reduced by removal of underlying bone prominences.

The neurosurgeon may have to re-enter the picture if severe reflex involuntary contractions of the patient's spastic muscles develops. These can best be relieved by cutting the ventral motor roots of the cauda equina from the first lumbar down through the first sacral segments. This leaves the detrusor reflexes to

the bladder, which are mediated over the second to fourth sacral nerves, intact but converts the crippling flexor spasms of the legs to a far less handicapping flaccid paralysis. For adductor spasm, obturator neurotomy alone is sufficient. Patients who suffer severe radicular pain in the arms from compression of spinal roots can often be helped by late decompressive laminectomy with resection of epidural scar tissue and projecting fragments of bone. We have recently been forced to carry out an extensive thoracolumbar sympathetic denervation to relieve a patient with the unusual complication of uncontrollable reflex sweating over his body and legs with accompanying bouts of hypertension and headache.

While recovery of visceral function can take place to a remarkable degree under spinal reflex control, there may be no recovery of the lower extremities and only partial use of the arms. Shoulder abduction and flexion of the elbows are the rule in all surviving patients. In these lower cervical injuries, a great deal depends on recovery of the seventh cervical segment. When this occurs the patient will have good use of his triceps and some ability to pronate and supinate his forearm, dorsiflex his wrist, and possibly to straighten his fingers and abduct his thumb. He can then get about in a wheelchair and often use his hands in a crude way. He will also have sensation in his thumb, index, and long fingers. A minister, with this degree of residual handicap for twenty years is able to type his sermons with his index fingers. Flexion of the fingers depends on recovery of the eighth cervical nerve and use of the intrinsic muscles of the hand on the first thoracic as well.

Those unfortunate quadriplegics who fail to recover any useful control of the hands or musculature that supports the trunk can be helped by orthopaedic procedures. Stabilization of the thoracolumbar spine by extensive bone fusion or implanting strips of fascia lata between the lower ribs and ilium prevents slumping of the paralyzed torso when the patient sits up. Tendon transplantations can often be utilized to restore flexion and extension of the fingers, as well as opposition of the thumb, and to correct clawing of the fingers. Lipscomb, Elkins, and Henderson in the October 1958 issue of The Journal have described how this can be done, utilizing the brachioradialis, extensor carpi radialis longus and brevis, flexor carpi radialis, and pronator teres muscles. These muscles in the forearm usually recover after injuries below the sixth cervical spinal segment and can be used to make many victims of quadriplegia more independent.

In order to regain the maximum degree of recovery these patients require expert rehabilitation, which is available only in the largest and best equipped hospitals. A few indomitable individuals have accomplished wonders on their own, such as the young man described by John Hilton whose dislocated cervical vertebrae can be seen in the museum at Guy's Hospital alongside his perfect pencil copy from an engraving of a Raphael madonna. This man, who in 1836 had fallen out of a tree and suffered paralysis below the level of the triceps, managed to support himself by making these copies, holding his pencil or a fine camel's hair brush in his teeth. While there are few mid-cervical quadriplegics who can match this accomplishment, there are many leading worth-while and happy lives at home with their families. Although readjustment and rehabilitation require several years at an expenditure of approximately $10,000 per annum, this is infinitely preferable to early death or permanent institutional care of the neglected cripple.

James C. White, M.D.

WHIPLASH—AN UNACCEPTABLE MEDICAL TERM

Disabilities of the cervical region, which develop as the result of either direct or indirect trauma, must be reviewed carefully in order to identify the anatomical structure involved and the specific nature of the involvement. The mode of treatment adopted must be based on indications which are commensurate with demonstrable pathological changes. Since specific pathological changes in definite anatomical structures develop following trauma to the neck, no matter what the cause of the trauma, specific localization and characterization of the pathological process is possible and on the basis of this information can be made definite estimations of the anticipated time for recovery and of any residual permanent damage. Hence there is no room, nor is there any reason for such a loose diagnosis as *whiplash injury of the neck*. This diagnosis is vague and thoroughly unscientific. Furthermore, its use may lead to extreme injustice to those responsible for causing these injuries due to the rather dramatic implications of this phrase. There is a tendency for this terminology to be employed either through lack of sufficient knowledge to make a specific diagnosis or for the purpose of exaggerating the severity of the original injury and the possible residual disability, in order to expand the benefits to be secured in legal action. The application of the term *whiplash injury* to the cervical region despite the lack of similarity of the cervical spine (a relatively short jointed structure, made up of separate rigid segments, with a ten-pound weight on its end) to a whip (which is long, unjointed, evenly flexible throughout its length, and has no weight on the end) is not a rational procedure. For this reason even changing the term to *whiplash mechanism of injury* is unacceptable. The neck is not a whip. There is no question but what injuries accruing to specific structures of the neck may be serious. The use of this term, however, has developed to such extent as to almost maliciously tend to magnify and prolong the actual effects of injury and to confuse patients, courts, and juries. While pointing out the actual, and sometimes the severe, injuries that involve the cervical region of the spine, we should at the same time attempt to "lay the ghost" of the *whiplash injury*. The term to the honest is merely a bulwark behind which ignorance skulks; to the dishonest a mirage with which to confuse and delude.

David M. Bosworth, M.D.

The Advantages of Early Spine Fusion in the Treatment of Fracture-Dislocation of the Cervical Spine*

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Internal fixation and spine fusion is not a new method of treatment for fracture-dislocation of the cervical spine, nor is it the only method that will give satisfactory results. However, it can be shown to have many advantages. The first operation of this type was done about sixty years ago, but it has been more widely used in its present form since 1937 to 1942, due to the influence and publications of such men as Cone and Turner, Gallie, Rogers [5], and Badgley.

In April 1957, Rogers [6] published a complete summary of his experiences with this method of treatment. In this critical end-result study of seventy-seven patients, with eighty-seven fractures and dislocations of the cervical spine, he showed that skull traction gave the best protection to the cord during the period of definitive treatment and that wire internal fixation, along with surgical spine fusion, provided the most reliable stabilization of the injured vertebrae.

We feel that it is appropriate at this time to emphasize the advantages of this type of treatment for fracture-dislocations of the cervical spine because of the increasing frequency of these injuries, associated with the increasing automobile-accident rate. Furthermore, the present trend in the treatment of fractures in other parts of the body is toward more internal fixation. In those areas we are striving for less deformity, less stiffness in adjacent joints and soft tissues, less morbidity, less external fixation, and early ambulation; consequently, greater comfort and mobility, a shorter period of confinement to bed or hospital, and less time away from work or other vital activities result.

The same objectives apply to the treatment of fractures of the cervical spine, but in addition, we have the most important consideration of all, the safety of the neural elements. Residual deformity of the bone structures, with narrowing of the diameter of the spinal canal, may mean continuing pressure on the cord, so we strive for complete reduction. Recurrence of the deformity might mean return of neurological changes, and could result in worse paralysis or even death; therefore, adequate fixation is important in order to prevent such a catastrophe.

Analysis of our cases indicates, as did Rogers', that the cord is protected best with the patient in skull traction during the period of definitive treatment, that reduction of the bone structures is more complete and deformity less apt to recur following open operation with wire internal fixation, and that ultimate stability of the supporting elements is best assured by surgical spine fusion.

CLINICAL MATERIAL

Of the 105 patients with fracture-dislocation of the cervical spine, twenty-four were discarded as being unsuitable for this study. Some were transferred to

* Read in part at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N.Y., February 4, 1958.

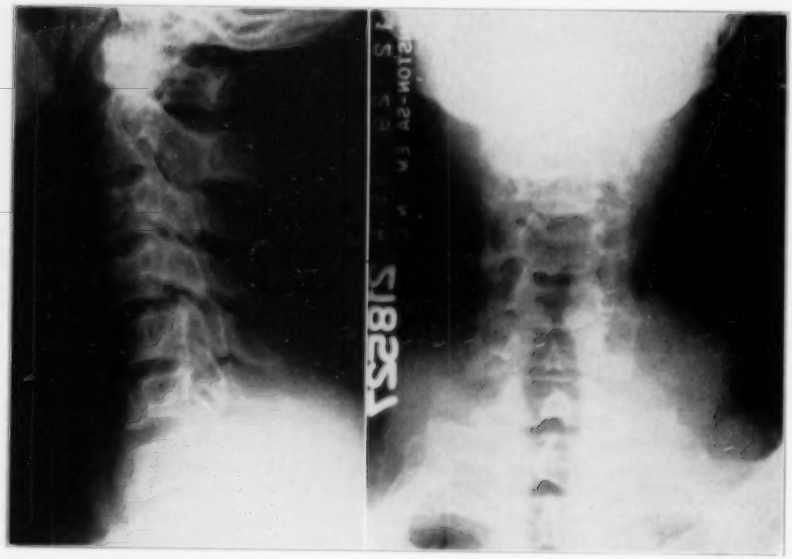

FIG. 1-A

Unilateral fracture-dislocation of the fourth on the fifth cervical vertebra.

Military or Veterans Hospitals within a few days after the injury, and before any definitive treatment was started, except to place them in skull traction or other protective device as indicated. The others were seen several months or years after the injury and, although further treatment was rendered, including spine fusion in some instances, they did not fit into this statistical analysis of treatment in the acute phase. This left eighty-one patients who were considered for internal fixation and spine fusion early in their course of treatment. In three of the patients who were treated without fusion, recurrence of deformity developed; fusion was subsequently done. Thus a total of eighty-four cases were analyzed.

The average age of the patients in this group was thirty-three years, but they varied from eight months to seventy-five years. Seventy-two of the patients were male, and only nine were female. An automobile accident was by far the most frequent cause of these injuries, accounting for fifty-one of eighty-one injuries, while falling produced twelve, diving six, gunshot three, and all other causes nine.

The severity of injury is fairly well illustrated by the fact that fifty-two of the patients had neurological changes when admitted to the hospital as compared with twenty-nine who had none. Twenty-three of eighty-one patients had injuries of the first or second cervical vertebra, while in the remaining fifty-eight the injuries were below the second cervical vertebra.

Death occurred in seven of the eighty-one patients during the acute post-injury phase of treatment. Five deaths were due to severe head injury, one to extensive infarction of the cord sixteen days after injury, and one to pulmonary embolism fifteen days after cervical occipital fusion for pathological fracture of the odontoid from carcinoma of the prostate. Death occurred in four tetraplegic patients from seven months to three years after injury due to pulmonary infection. Only one of these had undergone spine fusion.

METHOD OF TREATMENT

There was some variation in the methods of treatment used in these patients since several members of the Staff as well as the House Staff were involved.

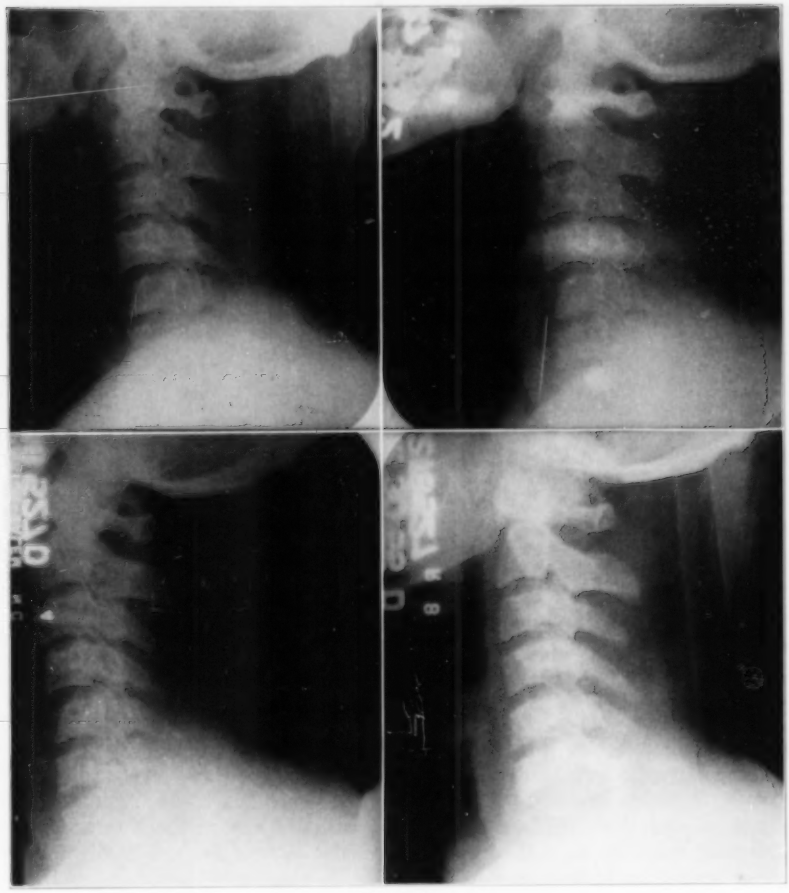

FIG. 1-B

Progressive reduction with thirty-five pounds of skull traction. Roentgenograms were made at three-hour intervals.

Experience has taught us many things, but one of the most important is that cooperation of the Orthopaedic and Neurosurgical Services in the care of cervical-spine injuries leads to better results. This is particularly important in the teaching centers, where the Residents on each Service need know and understand the point of view of the other Staff as well as their own. Practically all of the patients are seen by both services; recommendations for treatment were discussed jointly; and, if surgery was indicated, it was usually done as a combined procedure.

Extreme care must be taken in handling these patients. If a cervical spine injury is suspected, five to seven pounds of head-halter traction should be applied in the Emergency Room before moving the patient to the X-ray Department. If a patient has an obvious cervical injury with significant neurological involvement, fifteen to twenty pounds of skull traction is applied by means of Crutchfield tongs before he leaves the Emergency Room. The direction of traction should be straight until satisfactory roentgenograms have demonstrated the type and location of the injury. A horizontal beam lateral roentgenogram is made before the patient is moved from the stretcher. Anteroposterior, lateral, and oblique views of the cervical spine, as well as an open-mouth view of the odontoid process, should be made subsequently. Occasionally stereoscopic films, planograms,

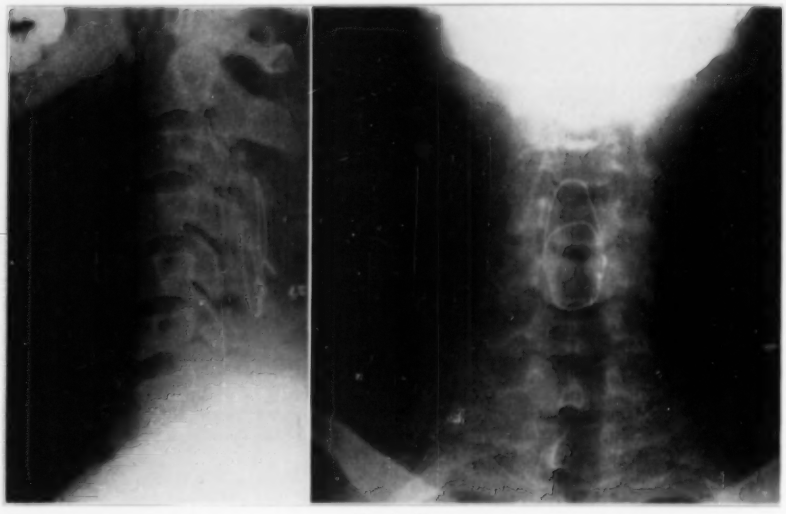

FIG. 1-C

Postoperative roentgenograms show internal fixation and spine fusion.

and flexion-extension lateral and oblique views are necessary; but these should not be made until the routine films have been interpreted by an expert. Flexing or extending an injured cervical spine might be disastrous, but a straight pull has proved safe, without exception, in our experience.

If there is severe cord damage, the patient is placed on a turning frame; but if the neurological involvement is slight, he is placed in bed on a foam rubber mattress on boards. Reduction of the deformity is then attempted by skull traction, from ten to forty pounds being used depending on the type of lesion. In patients with little displacement or in whom reduction was easy, traction was maintained with ten pounds of weight until the patient was ready for a brace, cast, or operation. In the other patients, such as those with anterior dislocations with locking of facets, which are hard to reduce, twenty-five to forty pounds of weight was required for a short period of time (Figs. 1-A, 1-B, and 1-C). The progress of reduction was checked by roentgenograms made at intervals of fifteen to thirty minutes. If reduction was difficult, muscle spasm was controlled by relaxants. If there was a flexion type of fracture-dislocation, when the reduction was complete the neck was hyperextended by lowering the head over the end of the mattress which had been moved toward the foot of the bed about eight inches (Fig. 2). The weight was then reduced to about ten pounds and the position was again checked by roentgenogram. The amount and direction of the traction varied according to the type of fracture to be reduced; in our experience this method proved safe for the spinal cord and nerve roots. Reduction of the deformity occurs gradually in a controlled fashion, and in no instance did it cause or increase paralysis.

INDICATIONS FOR FUSION

We have no set rule for selecting patients for internal fixation and spine fusion. Our primary purpose is to protect the cord and nerve roots; therefore we tend to stabilize those fractures in which residual or recurrent deformity might occur and which might in turn give pressure on the neural elements. Fractures of the odontoid process with displacement, and rupture of the transverse ligament of the atlas with atlanto-axial dislocation are lesions that, at least

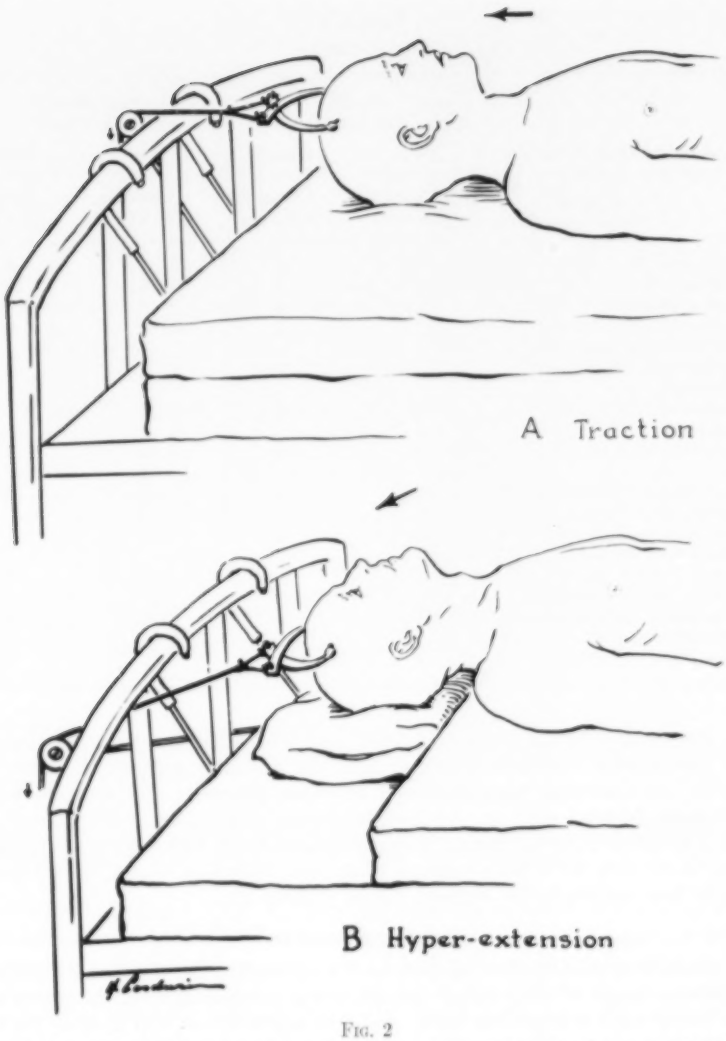

FIG. 2

Diagram shows: *A*, straight skull traction by means of Crutchfield tongs and, *B*, hyperextension position after reduction.

hypothetically, heal poorly, redisplace easily, and carry a high rate of neurological morbidity when they do recur; we fused fourteen of eighteen cervical spines in this group. The other four patients either refused operation or were judged to be poor surgical risks because of severe head injuries or poor general health. Fracture-dislocations, with one or both articular processes fractured, are difficult to immobilize; fusion is therefore frequently done in this group. Twenty cervical spines were fused and twenty were not; of the twenty patients in whom cervical spine fusion was not done, five died of severe head injury, two were transferred to Veterans Hospitals, two were subjected to fusion later, two had decompression without fusion because of severe cord damage, three had minimal fractures and did not require fusion, while one refused the operation (Table I).

There are two major groups of injuries in which fusion is seldom required:

1. Flexion injuries, with only compression fracture of the anterior part of the

TABLE I

TYPE OF INJURY

Type of Bone Lesion By Roentgenographic Appearance	Fusion (38 Cases)		Non-Fusion (46 Cases)	
	With Neurological Changes (25 Cases)	Without Neurological Changes (13 Cases)	With Neurological Changes (29 Cases)	Without Neurological Changes (17 Cases)
Total C1 and C2	6	10	3	4
Total below C2	19	3	26	13
Fracture of odontoid	5	6	2	2
Dislocation of C1 on C2 (torn transverse ligament)	1	2	0	0
Dislocation without fracture (unilateral)	2	0	1	0
Dislocation without fracture (bilateral)	0	1	0	1
Compression fracture of body only	0	0	5	4
Rotatory fracture-dislocation with unilateral facet fracture	5	1	2	2
Anterior fracture-dislocation with bilateral facet fractures	12	2	11	5
Fractured "small parts" only (pedicles, laminae, spines)	0	1	0	3
Chip fracture of body or anterior longitudinal ligament tear	0	0	6	0
No bone lesion by x-ray	0	0	2	0

body, can usually be corrected fairly well and held safely until they are healed. Other compression fractures which involve the posterior part of the vertebral body, or are combined with fractured articular processes, are dangerous and may require fusion.

2. Extension injuries, though frequently associated with severe neurological lesions, show very little bone damage. They are, therefore, easier to immobilize and will heal satisfactorily without fusion (Table I).

OPERATIVE PROCEDURE

Operation is usually done as soon as the patient's general condition permits. The average length of time before operation was thirteen days in the group as a whole, but in some emergencies fusion was done much sooner, and in some patients in whom the cervical-spine injury was complicated by head injury or other fractures, fusion was done much later. A patient with an uncomplicated injury should be ready for fusion within one week. However, if there is a persistent block on spinal tap and a myelogram shows persistent pressure on the cord, immediate operation may be indicated.

The operation is done under general anaesthesia with an endotracheal tube inserted blindly through the nose, without removing the traction or tilting the head. The patient is placed on the table in the prone position with the face in the cerebellar head rest, and the neck straight with ten pounds of skeletal traction in place. The severely paralyzed patients are left on the anterior half of their turning frame while skeletal traction is continued. Even patients with old fractures in whom fusion is done late have Crutchfield tongs inserted and traction applied before operation, because we feel that we have better control of the head and neck during the operation and for about a week afterward.

Two different operative procedures are used, depending on the level and type of the fracture. We will describe the typical procedure for fractures below the

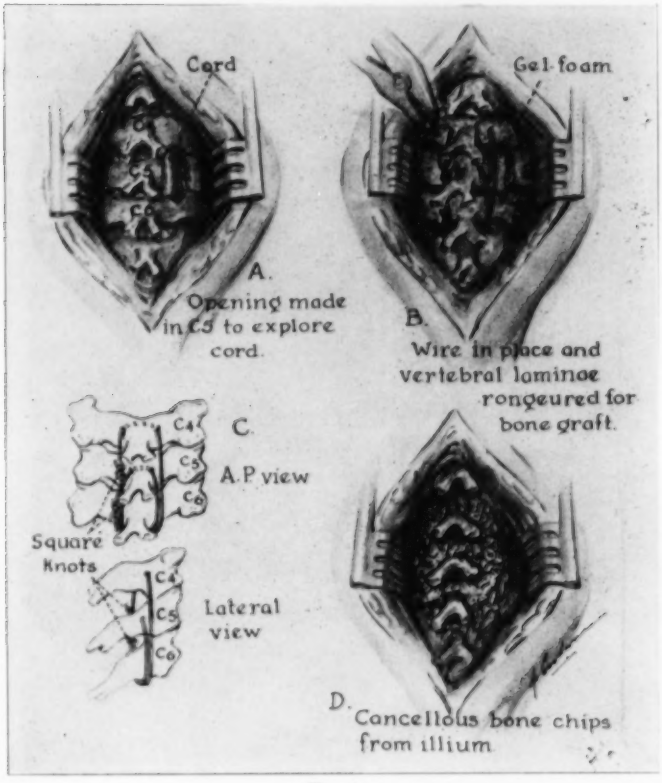

FIG. 3

Type of internal fixation and spine fusion done for fractures below the second cervical vertebra. At the present, match-stick grafts are used instead of chips.

second cervical vertebra (Fig. 3). In either type the exposure is made by sharp dissection in order to avoid the use of pressure and force. It is carried out to the posterior articulations on each side. The ligamentous attachments are removed with a rongeur, and the outer cortex of the laminae of the vertebrae to be fused is carefully nibbled away with small bites with the rongeur. No pounding is done at any time, because we feel that pounding is the cause, along with other rough handling, of the complications which may arise if this operation is improperly done.

Where indicated, a hemilaminectomy is done to inspect the cord and to decompress it or to look for a ruptured disc or bone fragment that is causing persistent pressure. If complete reduction of the fracture-dislocation has not been obtained by traction, it can now be done under direct vision, ensuring that no harm is done to the neural structures. If any doubt remains about either the reduction or the level of fusion, it should be checked by portable x-ray at this time. Internal fixation is then accomplished with 20-gauge stainless-steel wire. In fractures below the axis, the spinous processes of three vertebrae are usually wired together. The wires pass under the base of the spinous process of the lowest fractured vertebra if it is intact, and then through holes made near the top of the base of the spinous processes of the next two vertebrae. After placing a bone graft underneath them against the base of the spinous processes, the wires are tightened by twisting until they are snug and the whole group is

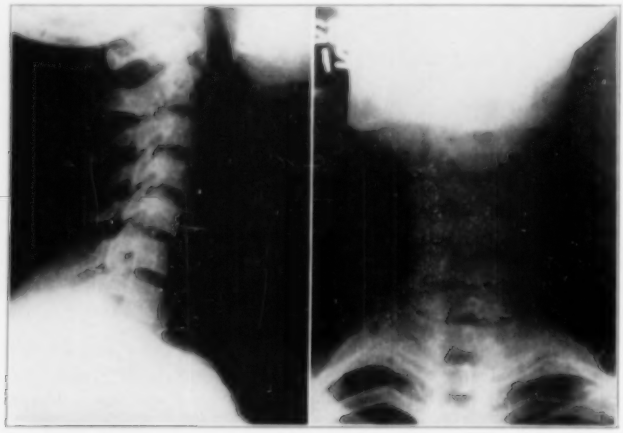

FIG. 4-A

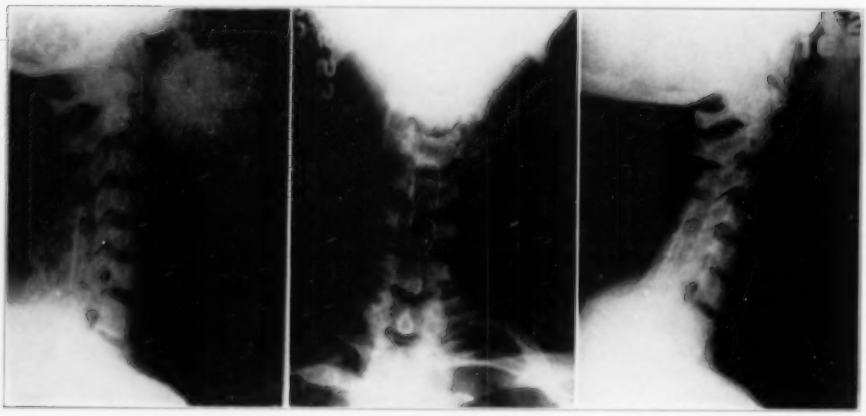

FIG. 4-B

Figs. 4-A and 4-B: Roentgenograms show unilateral fracture-dislocation of the fifth on the sixth cervical vertebra. The dislocation was reduced and the spine fused.

stable. More bone grafts in the form of match sticks are added to the fusion area, extending laterally over the laminae and posterior articulations on both sides (Figs. 4-A and 4-B). We formerly used finely divided bone chips for grafting, but now feel that the match-stick grafts heal just as readily and offer less danger of getting into the laminectomy defect. In the patients treated early in this series, we used autogenous iliac bone as the grafting material, and still feel that it is probably the best bone. However, for the last six or seven years we have used, almost exclusively, ribs from the bone bank, and have found them to be satisfactory. It reduces the time and shock of the operation to use this readily available bone rather than taking an iliac graft at the time of surgery. The spine fusions appear to be solid in four to six months, and we know of only one possible non-union. This man had a fractured odontoid process with a fusion of the first three cervical vertebrae. After six months, the graft was solid between the second and third cervical vertebrae but appeared to have been absorbed between the first and second cervical vertebrae. However, there was no demonstrable motion in flexion and extension films after one year.

The internal fixation varies slightly in certain cases. If the decompression has been more extensive, or if spinous processes, laminae, or pedicles are frac-

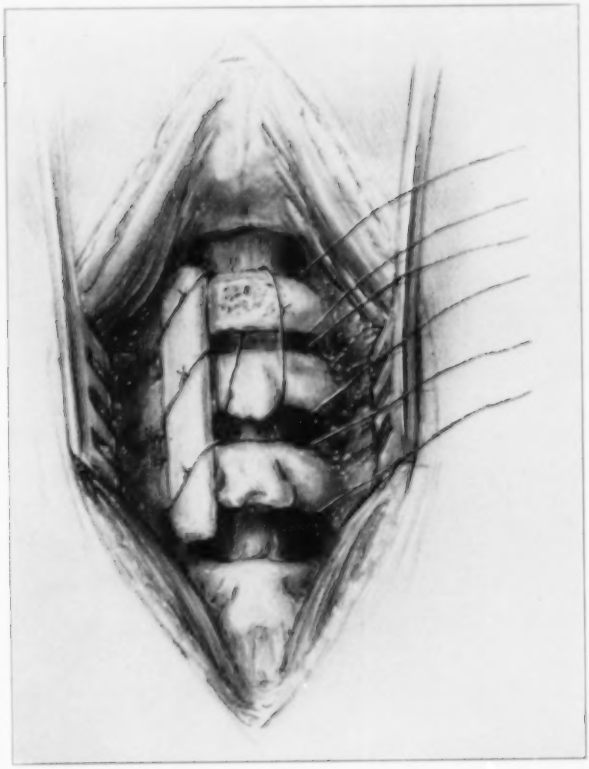

FIG. 5

Type of internal fixation and spine fusion used for fractures of the odontoid process and other fractures or dislocations of the atlas and axis.

tured, we may fuse four vertebrae instead of three. Sometimes we wire two laminae together on one side if the articular processes are fractured on that side. If they are fractured on both sides, the spine is probably quite unstable at that point, so we treat it like an odontoid fracture in which there may be likewise no bone block to prevent recurrence of dislocation.

The operative procedure for fracture of the odontoid process or tear of the transverse ligament with atlanto-axial dislocation involves wiring and fusing the first three cervical vertebrae (Fig. 5). In this area, we have not had to do a laminectomy. After denuding the spinous processes and laminae, a 20-gauge stainless-steel wire is passed under the laminae on each side of the first three cervical vertebrae. An additional wire is passed under the center of the posterior arch of the atlas and fastened tightly around the tip of the spinous process of the axis. Two pieces of rib or other cortical bone are so cut that their length corresponds exactly with the distance between the top of the arch of the atlas and the bottom of the lamina of the third cervical vertebra. The cortex on the under surface of the rib grafts is nibbled away with a rongeur in three places to correspond with the three laminae they rest on. One rib graft is placed on each side and is fastened securely to the three laminae by the three wires previously mentioned. Additional match-stick grafts are placed on each side, and the wound is closed (Figs. 6-A and 6-B).

By fastening the laminae of the upper three cervical vertebrae securely to

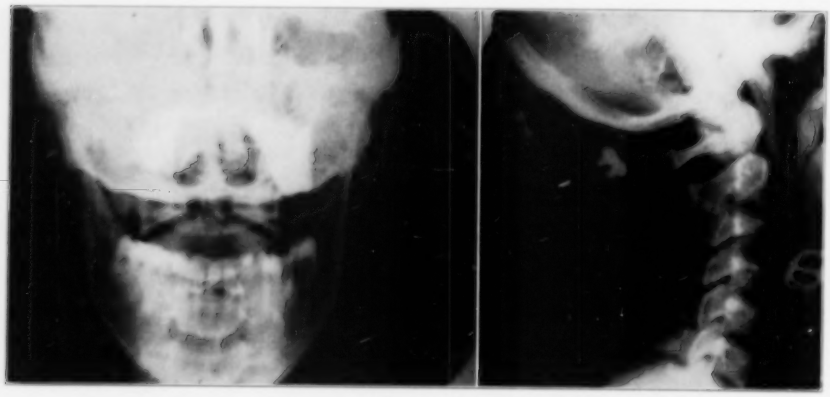

FIG. 6-A

Fracture of the odontoid process with slight posterior displacement.

FIG. 6-B

Postoperative lateral roentgenogram shows fusion of the first, second, and third cervical vertebrae.

the sturdy graft, we feel that there is very little chance that the atlas and odontoid process can redislocate on the remainder of the axis. There seems to be no point in including the occiput in such a fusion, but rather some disadvantage because it adds the weight of the head to what the wires and bone graft are already holding.

On the other hand, simply fixing the first two cervical vertebrae does not seem to be enough. It seems possible that displacement can still occur, and in the two patients in whom fusion was done this way early in the series, displacement did occur (Fig. 7). It seems that one needs the long lever arm fastened securely at two stationary points in order to hold the third point stationary when it is attached to it.

Postoperatively, five pounds of traction is applied for a week or ten days until the wound heals and the patient is comfortable. If the patient has little or no neurological change or other complications, he is usually up and about within

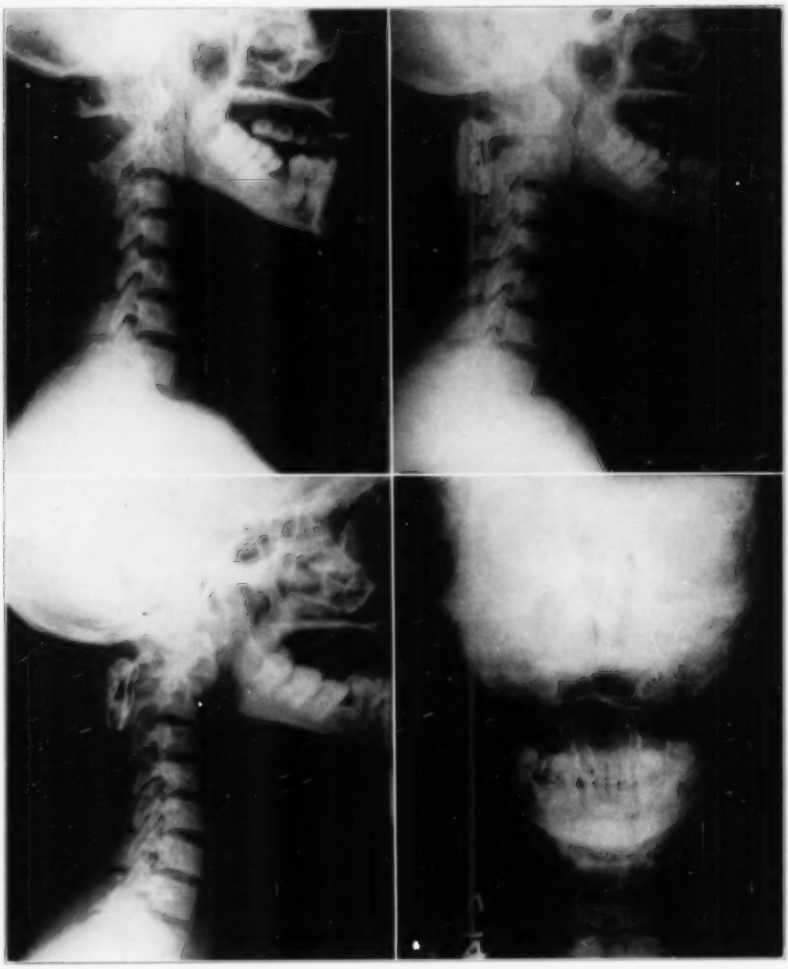

FIG. 7

Fracture of the odontoid process with slight anterior displacement. In the postoperative roentgenograms recurrence of anterior displacement is seen. Recurrence was a result of fusing only the first and second cervical vertebrae.

one or two weeks. In most instances he wears only a light cervical brace instead of a bulky Minerva cast. Most braces are removed in four to six months when the fusion is solid.

RESULTS

While trying to analyze the results in the eighty-four cases in our experience it soon became evident that one of the major factors that determined results, and particularly the length of time under treatment, was the question of neurological change. Consequently, each primary grouping of *fusion* or *non-fusion* has been subdivided for much of the analysis, depending upon whether the patient did or did not have neurological changes when he entered the hospital (Table II).

Including the three patients in whom fusion was done after a trial of conservative treatment (therefore counted in both the *non-fusion* and the *fusion*

TABLE II

NEUROLOGICAL CHANGES

Neurological Changes	Fusion	Non-Fusion
Present	23	29
Absent	15	17
Complete recovery	12	7
Improved	6	10
No improvement	4	6
No record	1	6

TABLE III

THE TIME ELEMENT

	Fusion with Neurological Changes (23 Cases)	Non-fusion with Neurological Changes (29 Cases)	Fusion without Neurological Changes (15 Cases)	Non-Fusion without Neurological Changes (17 Cases)
		(Average for Group)		
Days in bed	34	53	23	13
Days in hospital	39	49	26	16
Days in traction	27	27	18	14
Months in cast			2	2.8
Months in cervical brace	3.7	5.1	4.5	2.7
Months out of work	6.3	7.9	5.3	4.6
Patients who wore cast	3	2	1	6
Did not return to work	2	6	1	0
Deaths	1 (Late)	6 (Early) 3 (Late)	1 (Early)	0

group), there was a total of eighty-four cases. There were thirty-eight patients treated by internal fixation and spine fusion, and forty-six treated by other methods. Neurological changes were present in twenty-three of thirty-eight patients in whom fusion was done and were absent in the remaining fifteen patients. The results are shown in Table II.

In the non-fusion group (forty-six patients), there were twenty-nine with neurological changes and seventeen without. The results in this category are also shown in Table II.

The time factor in relation to various treatments and to neurological complications is shown in Table III. Only three of the patients having neurological changes who underwent fusion ever wore casts, two of them had sustained fracture of the odontoid process. In these only the first and second cervical vertebrae were fused. Recurrence of the deformity forced us to apply a cast. A third cast was applied as a precautionary measure because the patient's bone was found to be osteoporotic at the time of operation and we were afraid the wires might pull through. An average of 3.7 months of wearing a cervical brace and 6.3 months out of work does not seem excessive. Two of the patients did not return to work; one remained completely tetraplegic and died a few months later in a local hospital; the other had fairly good return of function in his arms but remained paraplegic in his lower extremities; in spite of every effort at rehabilitation, he had no desire to work and he did not.

Only two of the patients with neurological changes but who were not operated upon ever wore casts (Table III); if they were paraplegic they were kept on

TABLE IV

PAIN, DEFORMITY, AND LIMITATION OF MOTION

	Fusion (38 Cases)	Non-Fusion (46 Cases)
Residual pain	1	6
Residual deformity	6	10
Recurrent deformity	4	12
Motion, normal	0	8
Motion, limited slightly	8	11
Motion, limited moderately	18	4
Motion, not recorded	12	23

frames long enough for the fractures to become partially healed (two or three months) and then sat up wearing a cervical brace or collar. Patients in this group averaged 5.1 months in a cervical brace and 7.9 months out of work. Six patients in this group did not return to work, all six being severely paralyzed. Four of them died from pulmonary or renal complications within a year or two after leaving the hospital.

One patient, who had no neurological changes and who underwent cervical fusion early in the series, wore a Minerva cast for two months following open reduction and internal fixation of a dislocation of the fifth on the sixth cervical vertebra, but he probably did not need it. The group, described in Table III, averaged 4.5 months in a cervical brace and 5.3 months out of work. One patient in this group failed to return to work because of a cerebral vascular accident which occurred at the time of his operation. He was sixty-nine years of age and had worked on a farm until his injury.

Six patients in the non-fusion group and without neurological changes (which constitutes the least severe group of injuries) wore Minerva casts for an average of 2.8 months. The group averaged 4.6 months out of work (Table III).

Pain, deformity, and limitation of motion are recorded in Table IV. In the fusion group of thirty-eight patients, there was only one with residual pain, six with residual deformity, and four with recurrent deformity (practically all in the early years of our experience). Range of motion was not significantly limited. In the non-fusion group of forty-six patients, there were six with residual pain, ten with residual deformity, and twelve with recurrent deformity. We feel this is significant.

Statistics do not give an accurate picture of the time element in these patients. Too many unimportant things can alter the number of days in bed or hospital and months out of work. When conditions are favorable and everything goes well, a great deal of time and suffering can be saved by operation. For example, we cite the case of a nineteen-year-old male who suffered a slightly displaced fracture of the odontoid process, without neurological changes, when his motorcycle struck the curbing. He was admitted to another hospital; the fracture was reduced by head-halter traction; and he was allowed up in a Thomas brace. His deformity recurred within the week. He was transferred to our hospital, his fracture was reduced by skeletal traction; and fusion of the first three cervical vertebrae with internal fixation was performed the following day. He was up in a Thomas brace and home within two weeks; he was back to work as an office boy in one month. At six months the fusion was solid, his brace had been removed, and he was fully active. He had no pain, no neurological deficit, and about 25 or 30 per cent limitation of motion in his neck. There was no danger of belated neurological changes or death occurring from an unstable odontoid process.

Treated by other methods, this young man might have been placed in a Minerva cast for three months followed by a brace fixation for a similar period.

He might also have been treated by six weeks of skeletal traction in bed followed by two or three months in a Minerva cast and then a brace. He is certain to have lost four months from work and possibly more.

MECHANISM OF INJURY

The mechanism of injury is of the greatest importance, for only through a knowledge of the forces applied in each individual case is the proper management of that patient possible. A few minutes at the very outset devoted to learning the details of the accident are almost indispensable. Careful attention to the location of contusions and lacerations about the head may be the key to acquiring an understanding of the direction and intensity of the force applied through the head to the cervical spine. Knowledge of the mechanism of injury can lead

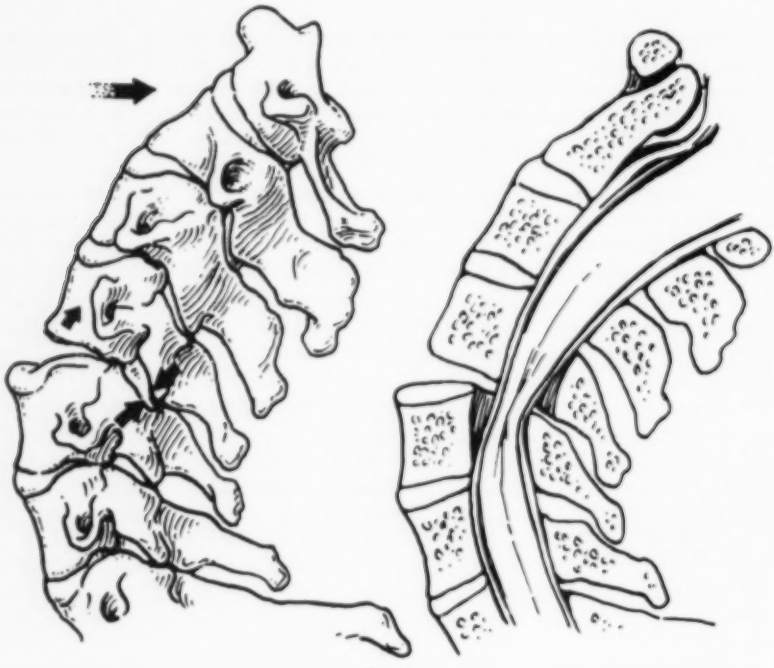

FIG. 8

Diagram shows lines of force in extension injury with posterior dislocation of the fourth on the fifth cervical vertebra with rupture of the anterior longitudinal ligament, separation between the vertebral body and the cartilaginous end plate, stripping of the posterior ligament away from the lower vertebrae, and carrying of the spinal cord backward against the sharp leading edge of the lamina of the subjacent vertebra.

to the correct interpretation of the roentgenograms of an accident victim. Such films, often made under difficult circumstances, are not always of the best quality, and it may prove of inestimable help to know what to look for.

The usual types of bone lesions, such as compression fracture of the vertebral body, anterior or rotatory dislocation or fracture-dislocation, bursting fracture of the atlas or other vertebral bodies, and fractures of the odontoid process with anterior or posterior dislocation of the atlas on the axis, are well understood and generally recognized lesions of the cervical spine. Since the excellent work of Taylor and Blackwood and of Barnes, published in 1948, we have learned to appreciate the importance of hyperextension injuries in the production of neurological damage, in the absence of x-ray evidence of significant bone damage. We now look carefully for the little chip fracture of the anterior edge of the ver-

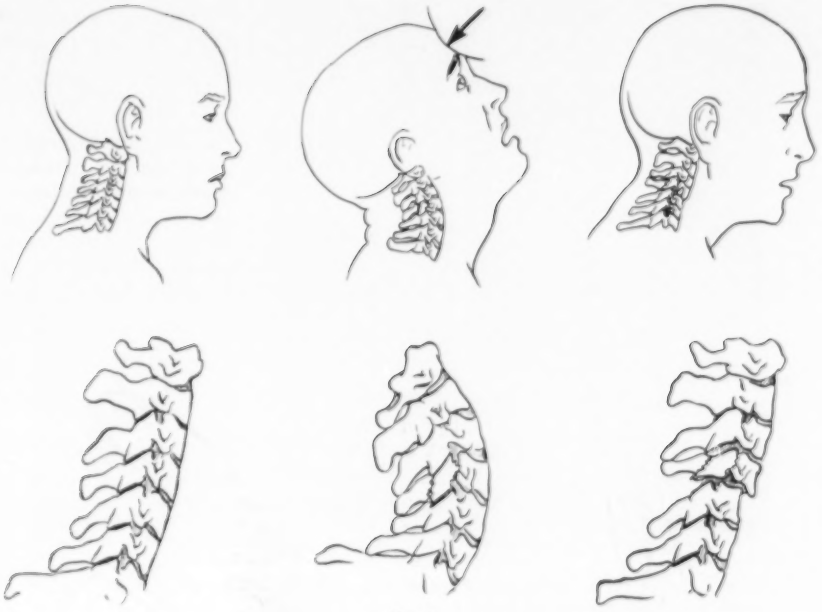

FIG. 9

Diagram of the mechanism of injury in the hyperextension fracture-dislocation showing direction of force, typical points of fracture, and final position of fractured vertebra. Points of interest are the anterior displacement of the fourth on the fifth cervical vertebra and upward compression of the inferior articular processes of the fourth cervical vertebra and its spinous process.

tebral body, which indicates the point at which the anterior longitudinal ligament ruptured, allowing the two vertebrae to separate. The mechanism of injury in all of these lesions is well established and does not require further emphasis in this paper. Instead, attention will now be directed to a group of injuries, heretofore unrecognized, caused by hyperextension and characterized by fractures of the posterior bone structures, including pedicles, articular processes, laminae, or spinous processes; and often by slight anterior dislocation of the vertebral body, either unilateral or bilateral depending on the direction of the fracturing force. It seems logical to designate these injuries as *hyperextension fracture-dislocations.*

Hyperextension fracture-dislocation is caused by a combination of forcible extension and compression acting from above. Until recently this type of injury was thought to result invariably in a fracture of the odontoid process or the posterior arch of the atlas or axis. These atlanto-axial fracture-dislocations, however, constitute but a small proportion of the hyperextension fracture-dislocation group. Fractures in the middle and lower parts of the cervical spine, can, and frequently do, result from this type of force. The fractures usually occur in the posterior elements of the vertebra, the so-called small parts which consist of the pedicles, articular processes, laminae, and spinous process. An important fact to remember about these fractures is that they are frequently multiple. The force, which is usually applied in the region of the forehead or anterior half of the skull, is transmitted to the cervical spine through the atlas and thence downward through successive sets of posterior elements until the force is spent. Thus, we frequently see fractures of the posterior arch of the atlas midway between the posterior tubercle and the lateral masses, or a fracture of the tip of the spine of the axis where it has impinged upon the spinous process of the third cervical verte-

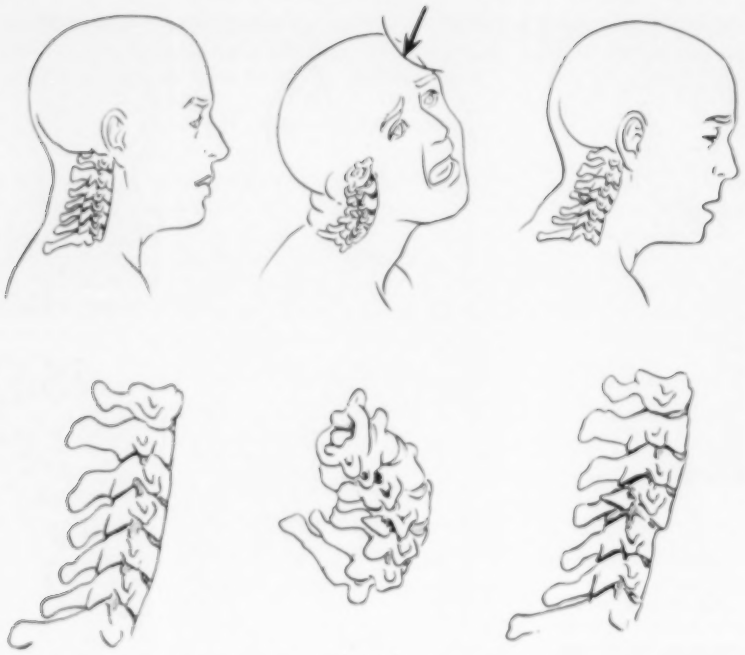

FIG. 10

Diagram of mechanism of injury in the rotatory hyperextension fracture-dislocation showing the direction of force, typical point of fracture, and final position of the fractured vertebra. In addition to the slight anterior displacement and rotation of the body of the fourth cervical vertebra, it is important to notice the horizontally displaced inferior articular process on one side of the fourth cervical vertebra. This horizontal articular process occurs on the side away from the point of injury and is invariably the inferior articular process of the upper or displaced vertebra.

bra or, of course, a fracture through the base of the odontoid process. In the mobile mid-portion of the cervical spine, the fracture is most apt to occur through the pedicles, articular processes, or the base of the spinous process. In the lower part of the cervical spine, the fracture may occur through the articular processes or laminae which are somewhat elongated and thin or in the distal half of the spinous process. It is not unusual to see fractures in two or three of these sites in the same patient. Fractures through the posterior arch of the atlas, the pedicles of the fourth cervical vertebra, and the tip of the spinous process of the sixth or seventh cervical vertebra might occur simultaneously; if one is seen, others should be looked for.

The most important fact to remember about these hyperextension fracture-dislocations is that in many of them the vertebral body is displaced anteriorly, and heretofore have always been mistaken for mild anterior (flexion) fracture-dislocations. The anterior displacement occurs in those hyperextension lesions which fracture through the pedicles or the articular processes. Since it is partly an extension mechanism, tending to tip the vertebra over backward, and partly a compression force, pushing together the articular processes, the end result is that the inferior articular processes of the vertebra above are compressed upward in relation to the vertebral body, and the body of that vertebra may become displaced forward. The spinous process may also be fractured at its base and displaced upward. At some point in this process the anterior longitudinal ligament may rupture, as evidenced by the chip fractures or late calcifications we have seen, but the vertebral bodies do not usually undergo a wide separation as they do in the posterior dislocations. In many ways this injury resembles the true

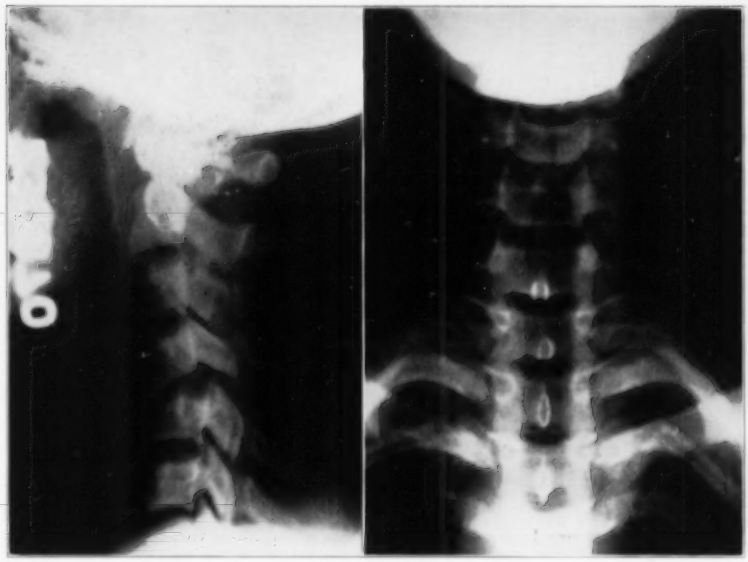

FIG. 11-A

Fig. 11-A: Case 1, R. H. Hyperextension fracture-dislocation of the fourth on the fifth cervical vertebra resembling a mild flexion injury. The patient was tetraplegic.

FIG. 11-B

Postoperative roentgenograms show satisfactory correction in the lateral roentgenogram on the left, although there is persistent compression of the articular mass of the fourth cervical vertebra. Lateral roentgenogram on the right shows some loss of position resulting from postoperative wound infection which caused the wire to pull out of the spinous process of the third cervical vertebra. The final result was satisfactory: there was solid fusion and partial return of neurological function.

anterior fracture-dislocation, but there are at least two distinguishing features. In the hyperextension fracture-dislocations, it is almost invariably the inferior articular process or the entire articular mass of the vertebra above that is displaced upward and backward, while in anterior fracture-dislocations it is the superior articular process of the vertebra below that is displaced downward and forward. The second distinguishing feature is the angle formed by lines parallel

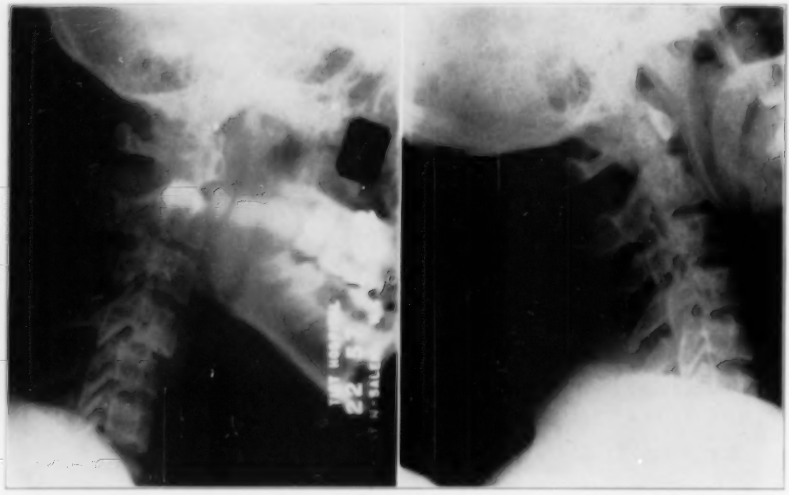

FIG 12-A

Case 2, C.S. Rotatory hyperextension fracture-dislocation of the fourth on the fifth cervical vertebra which resembled a mild rotatory flexion injury because of anterior displacement. He had a unilateral cord injury with motor loss below the fifth cervical on the right and corresponding sensory loss on the left. Note the unilateral horizontal articular process at the fourth cervical vertebra, present on the admission roentgenogram on the left and which persists in the roentgenogram made after reduction on the right.

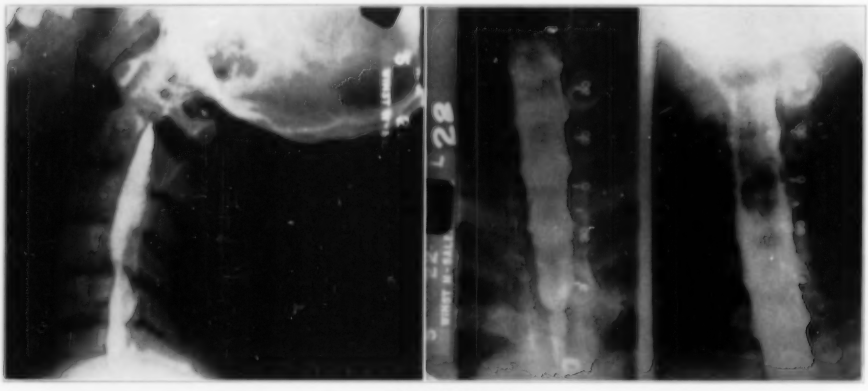

FIG. 12-B

Myelogram showing mild offset anteriorly between the fourth and fifth cervical vertebra, but a large defect posteriorly due to the displaced articular process.

to the inferior surface of the body of the fractured vertebra and its inferior articular process. The angle will be more obtuse in the hyperextension group when compared with the angle formed by similar lines on the normal vertebrae above and below it. In the anterior fracture-dislocations, the angle formed by these same lines will be approximately the same for all three vertebrae.

Another injury that has not been recognized heretofore is the rotatory hyperextension fracture-dislocation. The mechanism of injury is similar to that described for hyperextension fracture-dislocation except that in this the force comes from one side instead of from the mid-line. It combines forcible hyperextension and compression with rotation, and consequently the major strain is placed on the articular processes on the opposite side from which the force is coming. Each vertebra is forced backward and downward toward the opposite side on its fel-

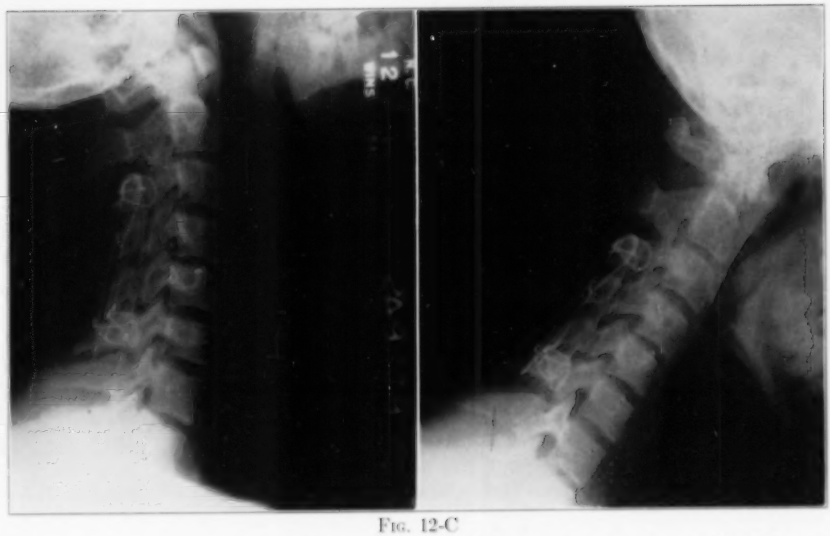

FIG. 12-C

Lateral roentgenograms made after reduction inflexion and extension show stable fusion at four months. Neurological recovery was almost complete.

low below until something gives away, usually in the more mobile segment (fourth, fifth, and sixth cervical vertebrae). The inferior articular process of this vertebra is fractured and displaced upward, outward, and backward so that it assumes a horizontal position that is easily seen on roentgenograms. This unilateral horizontal articular process, which is invariably the inferior one on the displaced vertebra, has been our most reliable diagnostic sign.

Injuries of this type are unstable up to a point and are frequently hard to reduce completely or to maintain in satisfactory reduction because of the loss of bone support when an articular process is displaced. Internal fixation and spine fusion is frequently necessary in order to give a stable, painless result. In the final analysis of our cases, we found this rotatory hyperextension mechanism at work in five of nine of our group of unilateral fracture-dislocations, while only four were caused by flexion.

The mechanism of these rather obscure types of lesions can be shown best by means of several examples.

CASE 1. R. H., a sixteen-year-old white boy, dived into the water and hit another boy just under the surface. He was conscious and knew that he struck on his forehead so that his head was forced backward into hyperextension. Roentgenograms showed what seemed to be a flexion injury with mild anterior dislocation of the fourth on the fifth cervical vertebra without locking of either articular process (Fig. 11-A). Barnes[2] showed that neurological damage could not occur in this type of injury without sufficient displacement to cause locking of one or both articular processes. The boy was tetraplegic. His injury was caused by hyperextension and compression. The fourth cervical vertebra was forced backward on the fifth, causing fractures of the base of the spinous process and upward compression fractures of the inferior articular processes of the fourth cervical vertebra (Fig. 9). The anterior longitudinal ligament ruptured at some point in this process, but not until the compression forces had done their damage posteriorly. The fact that later anterior fusion developed is evidence of damage to the anterior longitudinal ligament, even though there was no tell-tale chip of bone visible in the early roentgenograms.

In spite of a postoperative wound infection solid healing occurred, the neurological deficit partly cleared up, and his neck became stable and painless. Figure 11-B shows persistent compression of the articular mass of the fourth cervical vertebra.

CASE 2. C. S., a college student twenty-two years old, was in an automobile accident. His convertible turned over, and he suffered cuts and abrasions on the left side of his face and left ear, a minor cerebral concussion, a fracture of the cervical spine that resulted in

motor weakness on the right side of his body below the fifth cervical vertebra, and a corresponding sensory loss on the left. His head was forced into hyperextension and rotated toward the right (Fig. 10).

Roentgenograms of the cervical spine showed what appeared to be a rotatory anterior dislocation of the fourth on the fifth cervical vertebra (Fig. 12-A). A horizontal inferior articular process is visible on one side at the fourth cervical vertebra in the lateral roentgenogram made at the time of admission. Another lateral view showed that this persisted after reduction by skull traction. The patient had suffered a rotatory extension injury that reduced spontaneously and then displaced anteriorly because of lack of bone support to prevent it. The articular process remained in its position of deformity.

A myelogram was made the same day (Fig. 12-B) which showed only a mild offset anteriorly between the fourth and fifth cervical vertebrae and a large defect posteriorly due to the displaced articular process.

Following open reduction and removal of the bone fragment causing pressure on the cord, fusion of four vertebrae was done to prevent recurrence of the deformity (Fig. 12-C). Neurological recovery was almost complete. Four months later fusion appeared solid in lateral roentgenograms made in flexion and extension. The patient, incidentally, had returned to college in his "patched-up" convertible with his "patched-up" neck, very well satisfied with both.

SUMMARY

This paper is concerned with the advantages of internal fixation and spine fusion early in the treatment of fracture-dislocations of the cervical spine. It is based on a statistical analysis of eighty-four cases of this entity treated within the clinical experience of the authors. It is important to understand the mechanism of injury in each case in order to treat it intelligently.

In the treatment of cervical-spine injuries, first consideration must be given to protection of the neural elements. Relieving all pressure from the spinal cord and nerve roots, and putting them at rest, affords the best opportunity for return of function of the neural elements. To do this with certainty requires accurate reduction of bone elements, followed by internal fixation for immediate stability and spine fusion to prevent late recurrence. The general routine of skeletal traction, internal fixation, and spine fusion constitutes a method of treatment that needs to be varied but slightly in order to include a large percentage of all serious injuries of the cervical spine.

The results in thirty-eight spine fusions and forty-six injuries treated conservatively indicate that the patients in whom fusion was done had less residual deformity and a lower rate of recurrence. In addition less time was spent in the hospital or in uncomfortable casts, and less time was spent away from work.

The mechanism of injury in cervical-spine fractures and dislocations is discussed in some detail, with emphasis on the hyperextension types. A new interpretation of the roentgenographic findings in a large group of fracture-dislocations with mild anterior displacement shows that approximately half of them were caused by hyperextension rather than flexion as previously thought. Prior to the recognition of this mechanism, it was difficult to understand the severe neurological changes that were frequently present. Placing these cases in the group of hyperextension injuries makes the neurological damage understandable.

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Total Cervical-Spine Fusion for Neck Paralysis*

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Severe paralysis of the cervical muscles with residual instability of the head has, until recently, been an unusual and pathetic problem that stimulated only sporadic concern. Today the number of such patients has reached impressive proportions as a result of the dramatic increase in the survival rate to 85 per cent of poliomyelitic patients with respiratory paralysis [1], the streamlining of respiratory aids to allow patients to be upright and active, and the frequency with which involvement of the neck muscles accompanies respiratory impairment.

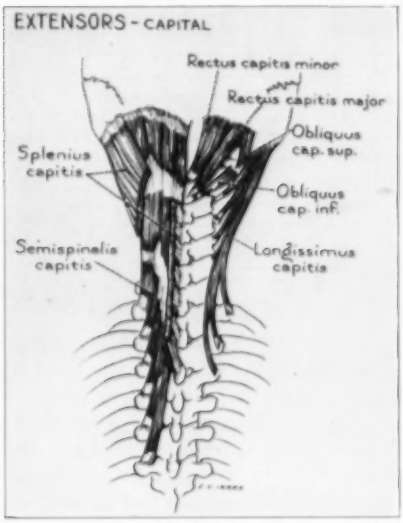

FIG. 1-A

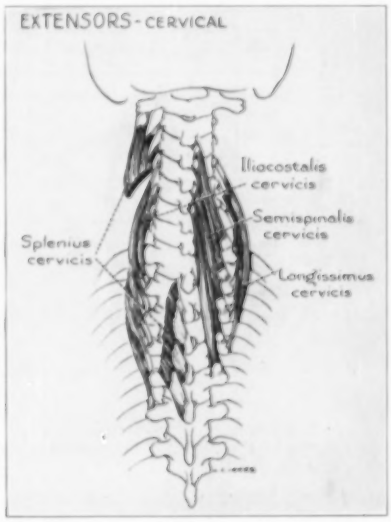

FIG. 1-B

While the recovery of muscle power in the neck is frequently sufficient to meet functional needs, there remains a significantly large group of patients with severe residual paralysis of the cervical muscles who have regained considerable use of their extremities and now need a stable head and neck for maximum activity.

In order to formulate a systematic therapeutic plan for this potentially active group of people, an organized study of the problem was initiated at the Rancho Los Amigos Poliomyelitis Respiratory Center. It quickly became evident that in addition to the obvious question of instability of the head the close relationship between position of the head and efficient function of the pharynx had to be considered, as a patient with partial paralysis of the pharyngeal muscles may lose all ability to swallow or speak if he is also unable to hold up his head. It is the purpose of this paper to present the results of this study of function of the neck muscles, as

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well as criteria for the diagnosis and management of the problems of both instability and malposition of the head.

The only reference we could find relating to cervical paralysis due to poliomyelitis was in the paper on complete muscle transplantations by Schottstaedt, Larsen, and Bost in 1955, although about 1918 there were two reports on temporary paralysis of the neck due to diphtheria [6, 7]. Through personal communication we have knowledge of four cases of cervical-spine fusion to replace the stability lost by paralysis due to poliomyelitis.

ANATOMY OF THE NECK MUSCLES

Close examination of approximately 100 patients with various patterns of paralysis of the neck has shown that the common broad grouping of the many cervical muscles into flexors and extensors must be further subdivided because control of the head is separate from that of the cervical spine. All the muscles acting on the head insert on the skull and shall be designated *capital* flexors and extensors, with the motion centered at the suboccipital and atlanto-axial joints. The term *cervical* flexors and extensors will be limited to the muscles which act

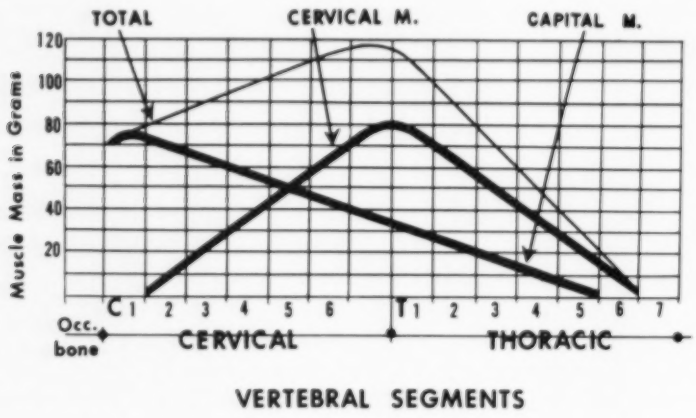

FIG. 2

A schematic correlation between the weight of the extensor muscles of the neck and the vertebral segments they overlie to indicate the relative force active at each joint.

only on the cervical spine, with motion centered in the lower cervical spine.

The capital extensor muscles are composed of four suboccipital muscles extending between the axis, atlas, and skull, and three large overlapping muscles which take origin from the sixth thoracic to the third cervical vertebra (Fig. 1-A). The cervical extensor mass is made up of four overlapping muscles which take origin from the proximal six thoracic vertebrae and insert on the second cervical to the sixth cervical vertebra (Fig. 1-B). A schematic interpretation of the relative extensor force active on each of the numerous joints in the neck can be formulated by correlating the weight of the individual extensor muscles [11] with the number of segments each muscle overlies. This scheme (Fig. 2) indicates that the maximum mass of the capital muscle group overlies the atlanto-axial joint, and that of the cervical group is opposite the cervicothoracic junction. Totaling the two groups, the maximum mass is shown again to overlie the cervicothoracic junction, suggesting that this is a major point of stress, with a second in the suboccipital area.

The flexors of the neck have the same basic anatomical pattern but the distribution is not as clear because a large portion of control of the anterior part of the neck comes from superficial muscles with other major actions.

The primary capital flexors are the short recti which lie between the atlas and

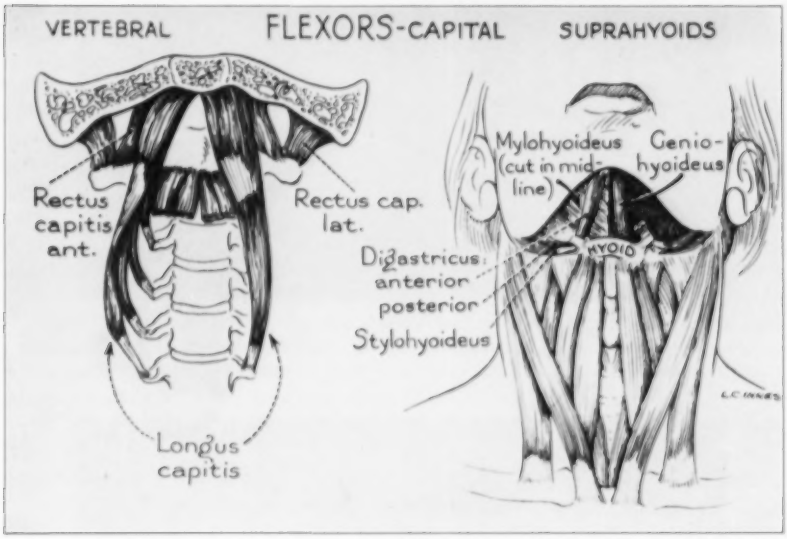

FIG. 3-A

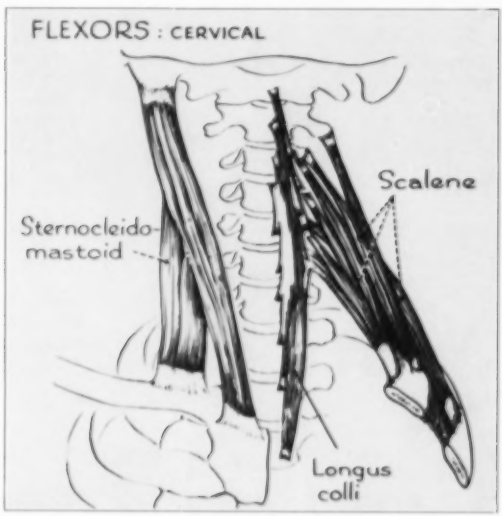

FIG. 3-B

skull and the longus capitis that takes origin from the middle cervical vertebrae. Reinforcing these flexors are the suprahyoid muscles from the mandibular area (Fig. 3-A).

The primary cervical flexors are the longus colli (a prevertebral mass), the three scaleni muscles which extend to the upper rib cage, and the sternocleidomastoideus (Fig. 3-B). It should be noted that the posterior insertion of the sternocleidomastoideus on the mastoid process makes this muscle a weak capital extensor unless the head has been pre-fixed in a flexed position. The infrahyoid muscle and the platysma are superficial accessory cervical flexors.

A schematic study of the flexor-muscle distribution, while less definite than the extensors, suggests that the maximum mass is opposite the fourth cervical vertebra, which is the apex of the cervical lordosis.

FIG. 4-A

Patient is attempting to sit up from the supine position. Because of the paralysis of his cervical flexors he is unable to raise his head despite strong suboccipital and upper trunk flexion.

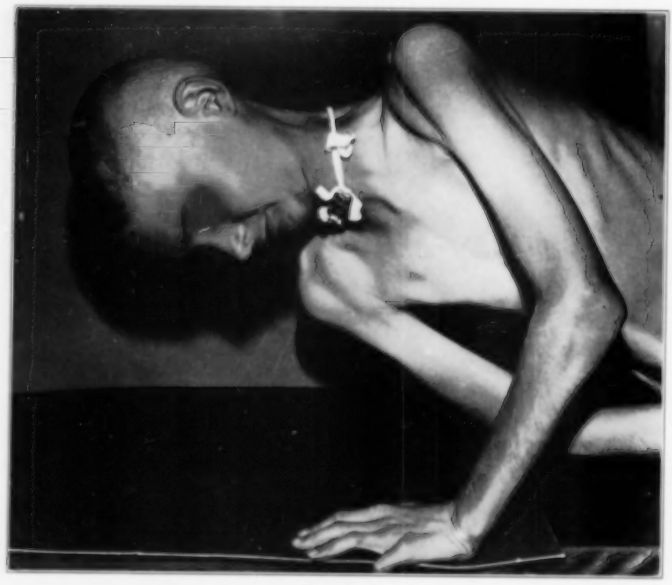

FIG. 4-B

By turning to the side, patient lets gravity substitute for the absent flexors of the neck and sits up without difficulty.

Individual evaluation of the four functional groups—capital flexors and extensors and cervical flexors and extensors—is necessary for effective management of nuchal paralysis.

HEAD INSTABILITY

The most obvious consequence of weak muscles of the neck is an unstable head. The apprehension and discomfort that accompany the head which drops in all directions when the patient is trying to sit up or stand, and especially as he moves about, is sufficient to curtail severely such activities. Patients with completely flail cervical spine will actually remain in bed despite good function of the extremities unless adequate support is supplied. Others who have partial control will assume various postural compromises which allow them to balance these unsteady heads. The substituting postures fall into rather definite patterns and are dictated by the particular group of paralyzed neck muscles. The rationale behind

this method of self-management is the fact that muscle strength of a poor grade is sufficient to balance the head in the upright position, but much more strength is necessary to meet the sudden changes of position that accompany the usual everyday activities, such as quickly bending over to pick up something from the floor or getting up from the supine position (Figs. 4-A and 4-B).

The most common site of paralysis is the cervical extensor group, resulting in increased flexion of the cervicothoracic junction. Overuse of the capital extensor muscles enables the patient to look straight ahead. This produces the well known postural picture of round shoulders, forward head, and acute capital extension (Figs. 5-A and 5-B). The patient notes no particular functional limitation other than the penalty of fatigue associated with the prolonged excessive use of the capital extensor group (the dowager syndrome).

In our experience, paralysis of the capital extensor group has always occurred in association with severe involvement of other muscles of the neck, either extensors or flexors (Fig. 6). The principal disability is related to the influence on the pharyngeal muscles, which will be discussed in the section on bulbar function.

When there is severe paralysis of all the extensors of the neck, the head is pulled or dropped forward and held anterior to the coronal body plane (Fig. 7). Overhead vision is accomplished by flipping the head up by extension of the trunk. There appears to be little discomfort to this anterior hanging position. Excessive flexion is prevented by the basic anatomy of the cervical vertebrae, which normally have a range of flexion that is less than half that available for extension, as indicated by Fielding's recent cinefluorographic studies. Also, the extensors of the neck are one of the many posterior muscle groups which tend to contract in response to the meningeal irritation in the acute phase of poliomyelitis. Unless deliberately stretched out, this shortening will persist as a convenient internal accessory support to replace the paralytic muscles—an illustration of a useful contracture which should be preserved. Enthusiastic stretching would do irreversible harm as a full range of motion is of value only when it can be actively controlled.

Involvement of the flexor muscles of the neck causes the greatest disability. When

FIG. 5-A

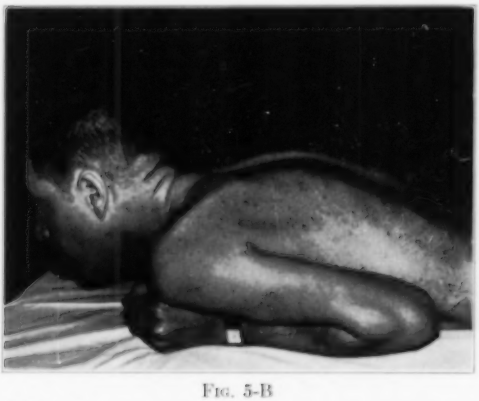

FIG. 5-B

Figs. 5-A and 5-B: Paralysis of cervical extensors.
Fig. 5-A: Typical standing posture.
Fig. 5-B: Head extension against gravity in the presence of strong capital extensors and paralyzed cervical extensors. Note sharp creasing in mid-cervical area and that the lower cervical area has not been raised.

FIG. 6

Extension of the head against gravity in the presence of paralyzed capital extensors and good cervical extensors. Note patient is still looking down rather than ahead.

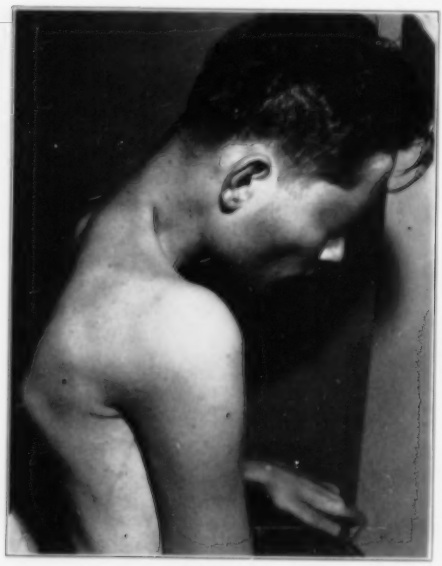

FIG. 7

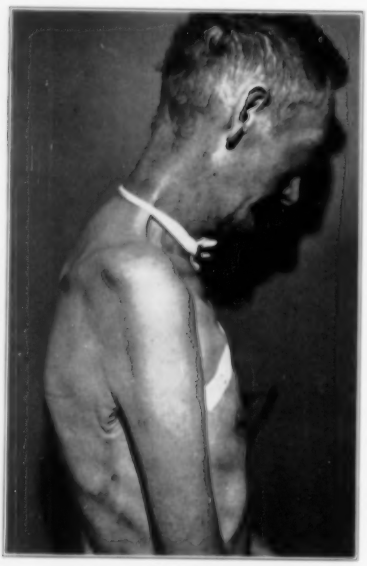

FIG. 8

Fig. 7: Patient sitting. All extensors of the neck are paralyzed, but flexors are good.
Fig. 8: The cervical flexor muscles are paralyzed. The patient assumes the position of hanging his head forward, using gravity to prevent extension.

the cervical flexor muscles are paralyzed, the patient assumes the position of hanging his head forward, using gravity to prevent extension (Fig. 8). Because extreme hyperextension causes considerable discomfort, as well as interfering with breathing and swallowing, all motions are done with great caution. A patient who has had several experiences of the uncontrolled head falling backwards becomes almost obsessive in his protective actions, even to staying in bed despite good function of the extremities.

The control of capital flexion is seldom lost. Presumably this is related to the presence of the suprahyoid muscles, which are innervated by cranial nerves, a level that is not frequently involved by poliomyelitis. Activity of the suprahyoid muscles is indicated by control of the floor of the mouth and the tongue, and by the

FIG. 9-A

FIG. 9-B

FIG. 9-A: Photograph shows patient sitting. Capital and cervical neck flexors are of a *poor* grade. As this is adequate for careful activity, little deformity is present. The increase of the thoracic kyphosis keeps the head anterior to the coronal plane. Good capital extensors keep vision straight ahead.

FIG. 9-B: Test of neck flexors against gravity: grade *poor*. Note upper portion of the trunk is flexed but head and neck remain extended. This inability to flex her chin to her chest would also prevent the patient from doing a sit-up, suggesting weak abdominal muscles.

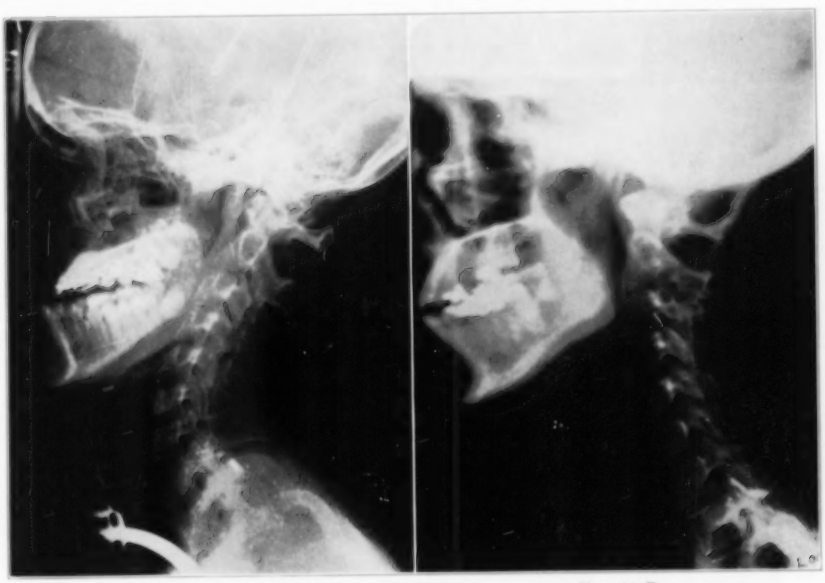

FIG. 10-A FIG. 10-B

Prognathism as a result of mandibular impingement on the apex of the cervical lordosis. It is readily corrected by proper positioning of the head.

unimpaired ability to swallow or speak. Adequate capital flexion seems to be absent only when there is also serious impairment of these bulbar functions.

With just the capital flexors functioning, the head is balanced in the erect position by strongly active capital flexion and passive exaggeration of the cervical

FIG. 11-A

Figs. 11-A through 11-C: A cinefluorographic study of glossopharyngeal breathing in a patient with the combination of severe bulbar and posterior cervical paralysis. Patient is supine on the x-ray table.

Fig. 11-A: No additional support under the neck or head. The capital flexion is indicated by the mandible overlapping the spine. The pharynx is occluded (arrow). No swallowing or glossopharyngeal breathing was possible in this position.

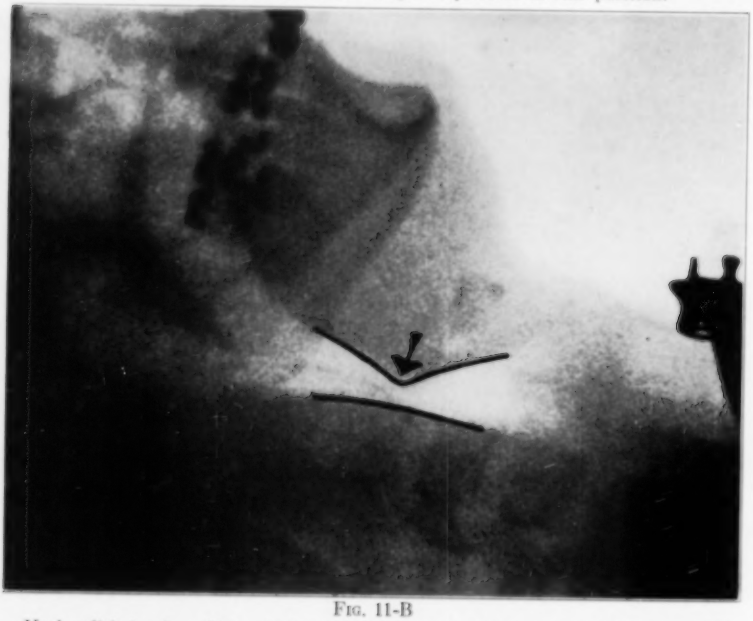

FIG. 11-B

Neck roll is in place. Note the increased patency of the pharynx and slight arching of the cervical spine. The neck roll serves to take the body weight off the head so the head may fall back into the more normal position. Adequate, but not good, swallowing was possible with the aid of the neck roll; glossopharyngeal breathing was poor.

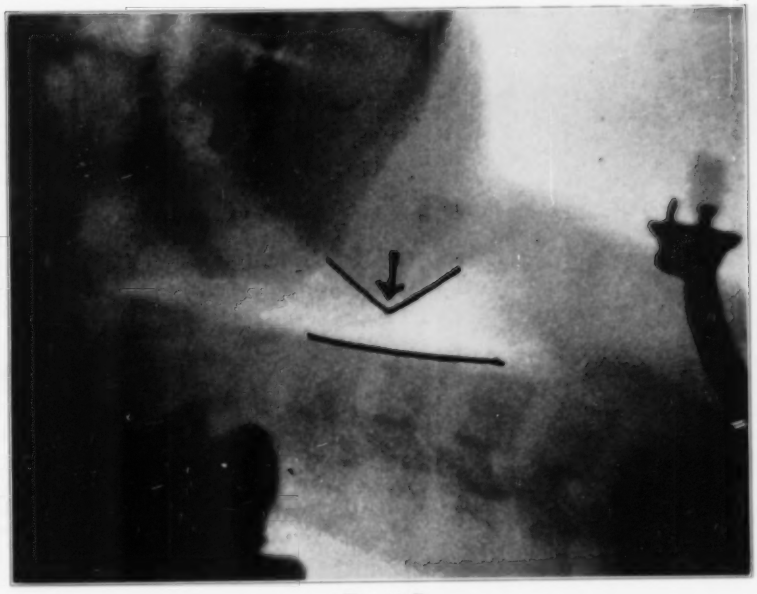

FIG. 11-C

The head is being held in good capital extension. Note the increased patency of the pharynx. The slight flexion in the mid-cervical areas illustrates how flail the posterior neck structures are, as this is just due to tissue weight. Good swallowing and glossopharyngeal breathing were possible.

lordosis and upper thoracic kyphosis (Figs. 9-A and 9-B). Several patients have become dependent upon a tracheostomy because of the increasing capital flexion and lower cervical lordosis causing a progressive impairment of the upper airway. Prognathism is frequently associated with this method of positioning as a result of mandibular impingement on the apex of the cervical lordosis. It is readily corrected by proper positioning of the head (Figs. 10-A and 10-B).

Aside from alterations in the anteroposterior posture which have just been considered, there is also the question of scoliosis due to asymmetrical lateral involvement. When there is unilateral involvement of either the capital or cervical muscles the head is pulled toward the stronger side, with a compensatory deviation of the trunk to the opposite direction, in an effort to level the eyes. Thus a marked scoliosis of the entire spine may be precipitated by unbalanced neck muscles. Of course these lateral deviations are more significant in children when there is sufficient growth still to be accomplished.

BULBAR MUSCLE FUNCTION

The muscles of the pharynx, larynx, and tongue are commonly referred to as bulbar muscles because their nerve supply comes from the bulb of the medulla oblongata at the proximal end of the spinal cord. Speech, swallowing, and the maintenance of a patent upper airway constitute the normal bulbar functions. To this one may add the learned technique of glossopharyngeal breathing, which may replace a mechanical respirator for several waking hours. These bulbar activities become the concern of the orthopaedist when there is weakness of the muscles of the neck in the presence of partial bulbar paralysis.

As previously mentioned, the capital extensors are the key group. When these muscles are paralyzed the head falls forward into acute flexion, passively shortening the bulbar muscles, as well as compressing the area by the weight of the posterior mandibular structures against the vertebral column. If the bulbar mus-

FIG. 12-A

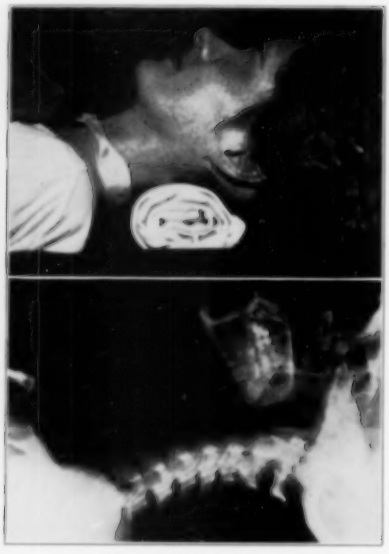

FIG. 12-B

Fig. 12-A: Patient supine on the table without additional support. Note, in the roentgenogram, the overlap of the mandible and cervical spine. The pharynx is compressed.

Fig. 12-B: Neck roll in place. Note elevation of the jaw as well as the cervical spine. The pharyngeal area is no longer obstructed.

cles are partially paralyzed and the position of the head cannot be controlled, all effective function may be lost and thus require permanent tracheostomy and gastrostomy.

A normal person can gain an impression of the influence of head position on these pharyngeal functions by trying to speak or swallow after dropping his chin onto his chest. The voice will have a lower pitch, and swallowing will become difficult. Manually positioning the head into extension in patients who already have this combination of paralysis, may show a dramatic improvement in volume of the voice unless prolonged malpositioning has allowed the development of significant contractures. Then improvement must await the correction of these deformities by proper positioning of the head and specific stretching exercises for the bulbar and neck muscles.

Cinefluorography of swallowing and glossopharyngeal breathing in patients with severe paralysis of the capital extensors and weak bulbar muscles clearly illustrates the influence of head positioning. As seen in Figures 11-A, 11-B, and 11-C, the pharynx is patent when the head is supported in capital extension but may be completely closed if the head is allowed to sag into flexion. These cinefluorographic studies seem to contradict Bosma's recent interpretation that support under the neck caused an obstructive cervical lordosis which aggravated the pharyngeal paralysis.

TREATMENT

As in the management of other aspects of paralysis from poliomyelitis, the first concern in treating involvement of the muscles of the neck is the prevention of deformity. Because a majority of these patients have a prolonged period of bedrest and relative inactivity due to their respiratory involvement, the most pressing problem is the suboccipital flexion which results from the weight of the head pressing against the bed. This is alleviated by substituting a neck roll or a butterfly pillow for the usual head pillow (Figs. 12-A and 12-B). The butterfly pillow

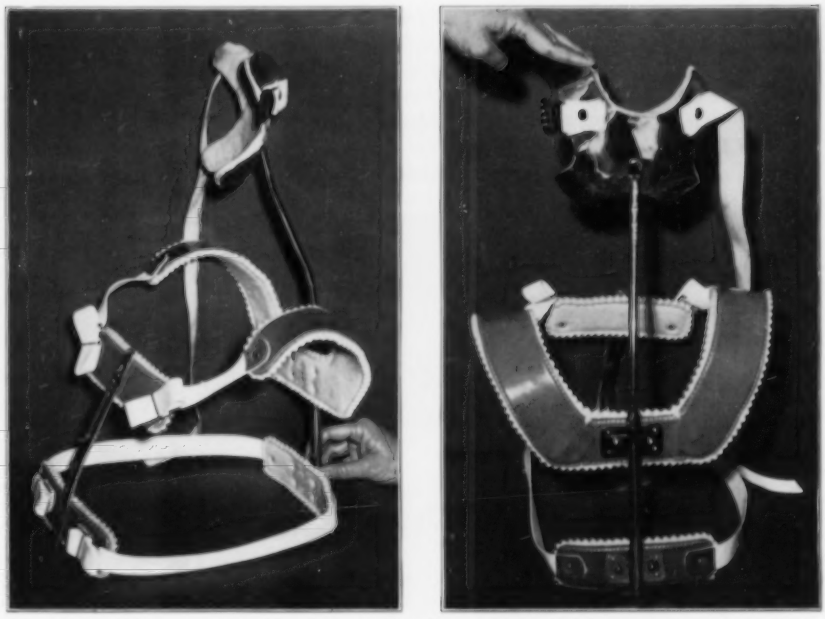

FIG. 13

Four-leaf clover adjustment applied to Benjamin-Taylor base.

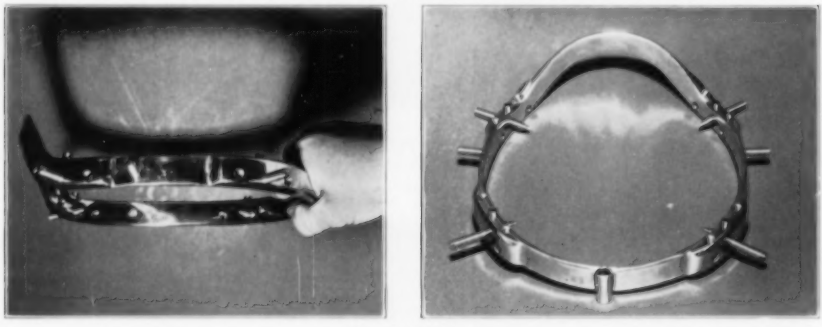

FIG. 14

The halo—anterior and lateral views.

also helps control lateral deviations. With severe loss of the capital extensors, special effort is made to keep the support just below the occiput.

The second objective of treatment is to give adequate stability and control of position to allow the patient to attain his maximum function potential. This has been approached in two directions: (1) bracing, and (2) the use of various surgical techniques.

Bracing

The most readily available braces for the support of the head are those designed to treat cervical-spine fractures. This type of brace suspends the head by support under the chin and occipital area with counterpressure on the shoulders. The inconveniences and discomforts of such a device are generally tolerated by patients with fractures when they realize its temporary nature and understand the dire consequences of a "broken neck". Pressure is seldom a serious problem because

this type of patient has adequate muscles to control and support his head, merely using the brace to prevent excessive motion of the cervical spine. Also, there is adequate function of the upper extremities to enable the patient to apply, adjust, or remove the brace at will.

In contrast, a patient with severe paralysis of the neck muscles must sustain the full weight of his head upon the chin and occipital supports. Aside from the discomfort of skin irritation, the restriction of jaw motion prevents adequate biting and chewing. In a child, considerable deformity and malocclusion can result from the prolonged pressure against the mandible. Attempts to alleviate the problem of chin pressure by making the brace either adjustable or relatively loose fail because of the lack of inherent support in the neck, the head merely dropping until it reaches the new position of the chin rest. The suspended head-halter is less irritating but also is too unstable to position the head for optimum bulbar function unless the patient has partial voluntary control.

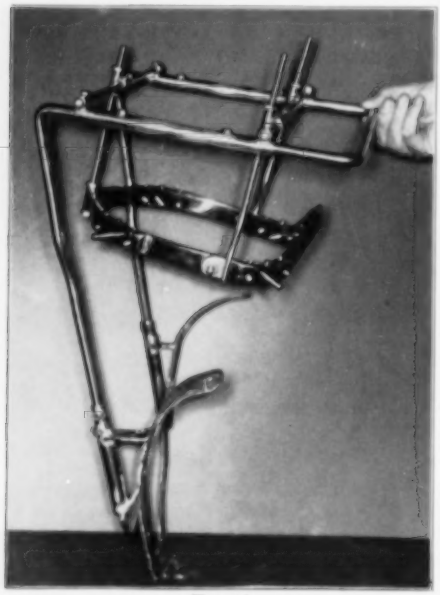

FIG. 15

Lateral view of the halo traction device. The V-shaped base will be screwed to the cast and the band reinforced by covering with plaster.

At Rancho Los Amigos Hospital a brace has been developed which avoids chin pressure by substituting a forehead strap for the chinpiece and changing the occipital cup to a four-leaf clover shape to provide more stability for the head. When the occipital support is well positioned under, rather than against the back of the head, very little pressure on the forehead is

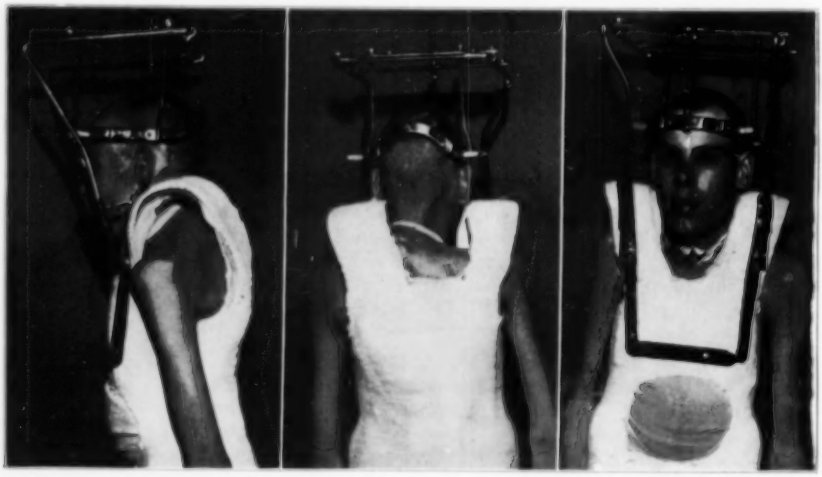

FIG. 16

Halo traction apparatus on a patient. The base has been fastened to the cast with screws but has not yet been covered with plaster.

required to maintain adequate positioning or balance, and significant suboccipital extension can be obtained for bulbar function.

This head support is balanced on a single adjustable posterior bar which is extended from either a removable body cast or a thoracic harness such as is used in the Benjamin-Taylor neck brace [2] (Fig. 13). The one disadvantage to this brace is that the rotatory deformities are not well controlled, and when this is a problem it has been necessary to revert to the chin support. However, all braces are restricting, uncomfortable, and far from attractive, so that most patients prefer to get by, if at all possible, by using one of the previously mentioned substituting postures and taking advantage of such tricks as turning sideways to get up from a supine position and limiting their scope of activity.

Thus, it is only the adults with severe paralysis or children who are being protected against scoliosis who remain in braces for a prolonged period. Without support both the children and adults tend to develop significant progressive postural abnormalities which become increasingly more rigid. In children there is the additional problem of bone deformity.

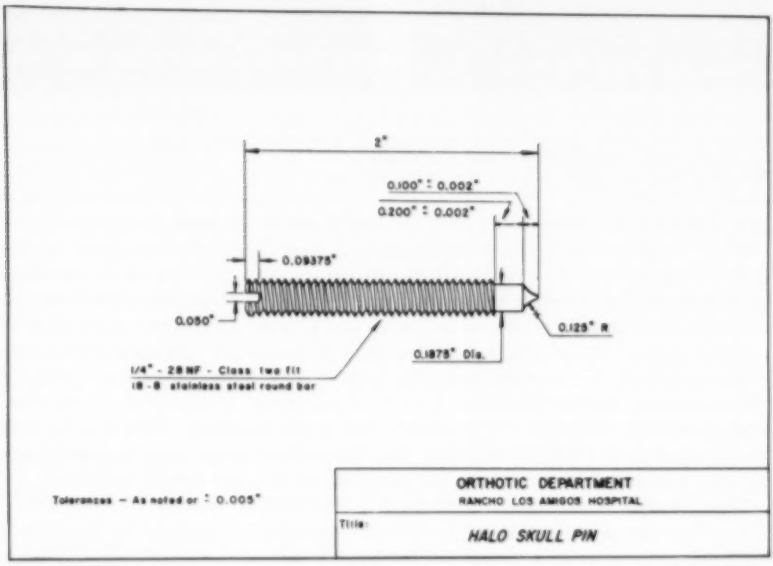

FIG. 17

Surgery

Properly selected surgery provides the most effective means of restoring stability and proper positioning of the head. Also, the problems of skin irritation, adjustment of braces, and dependence on others to apply the brace are eliminated.

Three types of surgery applicable to this problem are total muscle transfer, fascial transplantation, and cervical-spine fusion. Transference of the pectoralis major to replace the sternocleidomastoideus is an effective means of supplying flexion of the neck [10] and is indicated when the cervical flexors are paralyzed but capital muscles are adequate. The other requisite, of course, is the presence of transferrable muscles, a rare finding in patients with respiratory paralysis, as severe paralysis of the shoulder and shoulder-girdle muscles is almost always present. Patients with muscles just less than adequate for functional demands would profit from the added stability provided by fascial transplants as reinforcements. We have had no experience with these two procedures, but would use them in the

FIG. 18-A

FIG. 18-B

Figs. 18-A and 18-B: Lateral roentgenograms of normal cervical spines.
Fig. 18-A: Male: total cervical arc is 0 degrees.
Fig. 18-B: Female: total cervical arc is 45 degrees.

future if we should have patients who would meet the basic criteria.

With severe paralysis and its associated instability, fusion of the cervical spine is to be preferred. It is this most severe group which has been treated at Rancho Los Amigos Hospital. This method also has the advantage of being able to correct a faulty position as well as giving stability, so the patient may then take free advantage of the function that is present in the trunk and extremities.

The proximal limit of the cervical fusion is dictated by the strength of the capital extensors. Unless these muscles are at least good (that is, taking significant resistance when tested with the patient in the prone position), they will be inadequate to support the head independently. Thus when these capital extensors are weak, the fusion must extend to the occiput for a good result.

There is a strong tendency to leave the suboccipital area free for the range of rotation, but unless the patient has adequate muscles to stabilize his head he will not take advantage of this available rotation for fear of the head dropping, and in preference elects to turn the whole trunk when there is sufficient musculature of the trunk or lower extremities.

Initial timidity on our part to eliminate rotation required a suboccipital fusion as a second stage in our first patient, and upon completing this additional surgery, excellent function and a happy patient resulted. For these reasons cervical fusion is rarely indicated in patients having inadequate control of the trunk or extremities to substitute for the complete loss of head rotation. These more severely involved patients are confined to wheel chairs or bed and are able to make use of whatever active head rotation power is present by just stabilizing the head against the chair back, bed, or brace. Fusion of the suboccipital area would only be indicated when instability of the head is preventing adequate bulbar function.

In the presence of good capital extensors the proximal extent of the fusion is the joint between the second and third cervical vertebra, with care being taken not to distort the short suboccipital muscles by stripping the spinous process of the axis. The lower limit of the fusion is determined by the amount of stability of the trunk or scoliosis present.

When an unstable neck is the only problem, the fusion has been terminated distally at the third thoracic vertebra to assure good continuity between the fused area and the controlled area of the spine. This thoracic segment may be controlled either by active muscle power or the inherent rigidity of the unstretched post-

poliomyelitic spine. If there is a coexisting progressive scoliosis or unstable back, the cervical fusion is considered to be a proximal portion of a total spine fusion which may be extended as low as the fourth lumbar vertebra.

The biggest technical problem was one of adequate head fixation for the postoperative period in patients who had positioning difficulties due to impairment of bulbar function or a scoliosis. Skeletal cranial control was considered necessary from the first. Initially this was accomplished by means of wire passed through burr holes in the skull [8]. This method offered longitudinal traction, but poor control of rotation in either the coronal, sagittal, or transverse planes, and multiple alterations in the supporting plaster casts were required.

The problems of making minute postural changes within a large plaster cast to meet the demands of positioning for good bulbar function quickly indicated that a better method was essential. Fortunately, at this time we learned from Bloom of his apparatus for facial maxillary traction, which consisted of an aluminum tiara fixed to the cranium with screws. The advantages of this device for complete control of the head were apparent immediately. Changing the cranial portion to a full ring and making it of stainless steel provided the necessary additional strength (Fig. 14). This halo was then fastened to an adjustable counter-traction device which was fixed to the body cast (Figs. 15 and 16). By this means controlled traction and adjustment in all directions are provided. The skull pins have an offset which prevents excessive penetration (Fig. 17). They are easily applied by simple screwing without an initial incision, and can be changed readily under local anaesthesia. At present, three holes have been made in the halo for each of the four pin sites to allow changing of the pin in the event of a skin reaction.

The incidence and extent of reaction to the pins has been mild and relatively infrequent. The pins have frequently been left in for three or four months without any difficulties. As yet the longest time a halo has been used continuously is ten months. All the pins were changed once during this period.

Frequently a small amount of serous drainage is noted about the pin site, but this is usually controlled easily by daily cleansing with phisohex. If granulation tissue or cellulitis becomes evident, the pins are moved to a new site. Once the pins have been removed, the pin holes heal quickly without incident despite the closeness of the new insertion.

The cast is a typical body jacket, with the addition of shoulder straps. It is molded well about the iliac crest and against the convexity of the scoliosis, if such exists. The shoulder straps are sufficiently high to allow for the upward motion of the trunk when traction is applied. A large upper abdominal window is cut in the cast to relieve abdominal pressure while the patient is prone during surgery and for ease in eating and breathing.

Adequate time is allowed for complete and satisfactory positioning of the patient prior to surgery, with the changes being made in multiple small stages. The desired position has been determined as that which provides the optimum bulbar function, or in the case of scoliosis, when the head is balanced over the pelvis and the curve has been corrected as much as possible.

In an attempt to determine the normal position of the head and neck, roentgenograms were made of several of the younger employees with average posture and without history of neck lesions. The arc of the total cervical spine varied from 0 to 45 degrees, with considerable difference in the contour as well. No significant average was found, although the lordotic curve was consistently less in males (Figs. 18-A and 18-B). The suboccipital angle was measured between the longitudinal axis of the odontoid process and the base of the skull (as indicated by a line drawn between the floor of the sphenoid sinus and the junction of the occipital bone and mastoid process), by means of a lateral roentgenogram. This angle varied between 115 and 145 degrees, with the majority falling into the middle of the range.

An interesting consistency in this angle was also noted in the patients with

FIG. 19

Anaesthesia administered by intubation through the tracheostomy.

combined upper cervical extensor paralysis and partial bulbar involvement. Their usual resting position is at 90 degrees or less when bulbar function is obstructed. Manual positioning, bracing, and surgery have all produced useful bulbar function when an angle of 105 degrees has been attained.

As all of these patients with unstable necks had subnormal breathing capacity (50 per cent or less), an elective tracheotomy was performed prior to application of the halo and body cast, and the patient was trained to use positive pressure by tracheostomy for maintenance during the postoperative period. At the time of surgery this tracheostomy was also a convenient means of intubating the patient with the head locked in a rigid position (Fig. 19). This was necessary because all the surgery had to be done through a window in the cast with the halo in position in order to maintain accurately the desired position. A Mayo stand had been converted to a halo support to make the anterior part of the neck readily available to the anaesthetist and yet give adequate stability for the surgery (Fig. 20).

If no special positioning was required, a simple Minerva jacket was used for the postoperative immobilization if the fusion did not extend proximally to the second cervical vertebra.

The actual surgery consisted of the usual posterior exposure, with meticulous care being taken to stay in the mid-line raphe and to denude the vertebrae subperiosteally in order to minimize bleeding.

The subperiosteal stripping of the lamina was carried to the lateral margin of the posterior articulations, except at the atlanto-axial and suboccipital levels, where these joints lie anterior to the vertebral vessels. Because these vessels are slightly superolateral to the articulation between the second and third cervical vertebra, the medial edge of these posterior articulations indicates a safe lateral extent for exposure of the atlas and occipital bones. All the exposed bone was decorticated with a gouge, using the chip technique of Hibbs, with particular care being taken to disrupt the entire posterior surface of the posterior articulations. If the fusion area did not extend proximal to the second cervical vertebra, no additional bone was used. When the fusion was to include the atlas and occiput, multiple small chips of autogenous cancellous bone were added. This was taken from the

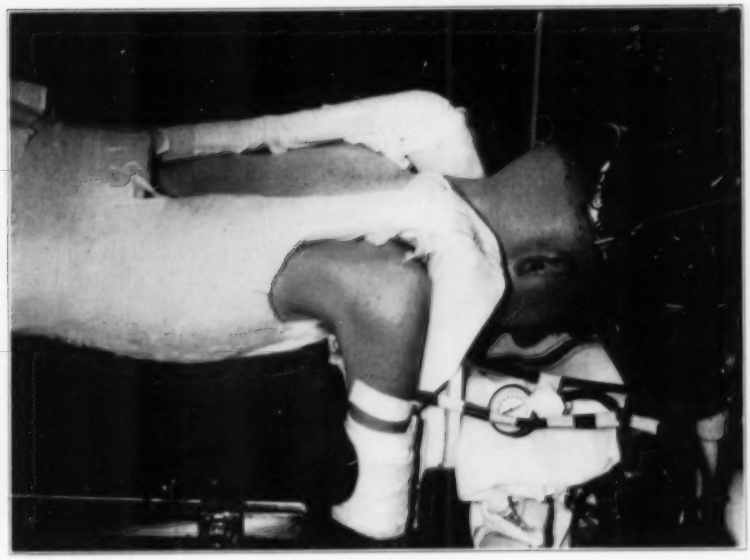

FIG. 20

Position of patient at surgery. Note the support under the halo.

posterior portion of the ilium at the time of the fusion. In any event, the cancellous bone chips were packed in the entire area extending from the occiput to the second cervical vertebra. Care was taken postoperatively to get adequate posterior pressure to prevent hematoma formation because the halo frame actually holds the patient's neck away from the bed.

The technical problem of denuding the cervical vertebrae has been greatly facilitated by the stability offered by the halo traction apparatus. This has enabled us to do the entire cervical fusion in one stage without difficulty. There has been no evidence of shock or damage to the spinal cord in our series.

The postoperative program has varied with the extent of the fusion. In all the patients skeletal traction has been maintained for three months. Patients with neck fusions only, whether or not the skull is included, are then transferred to a posterior padded plaster shell (Fig. 21), carefully molded to match the desired position. Straps across the forehead and chest hold the patient in the cast as desired. After approximately six weeks, the cast is discarded for increasing periods of time starting with one hour a day; but it is continued at night for at least three months, as the lying position produces the greatest constant stress due to pressure against the back of the head. A neck pillow is prescribed for an additional three months. This interval of partially decreased immobilization from that supplied by the halo encourages the more exuberant callus formation that tends to accompany the stress of very slight motion at an ossifying site, yet is absent when fixation is sufficiently rigid to eliminate these stresses or when there is an excess of motion [9]. The group of patients having just cervical or thoracic fusions were allowed to begin sitting up approximately one week following surgery. Generally these patients were fully ambulatory, without restrictions, by the end of the third postoperative week. When the fusion extended into the lumbar area, patients were kept supine for three months with their casts extending to the mid-thigh level bilaterally. A graduated program of sitting was then begun during the fourth month, reaching unlimited sitting or standing time by the end of the six-month period.

When a neck fusion is part of the total spine fusion for scoliosis, the skeletal traction has been maintained for the entire six-month period of solid cast fixation

FIG. 21

Fig. 21: Posterior shell used for support of the recently fused cervical spine after removal of the halo.

if the skin tolerance to the pins permits. Otherwise, a Minerva jacket is applied at the usual three-month interval. At the end of the six-month period of solid cast fixation, a removable body cast, including a head support, is then applied as part of the routine for the treatment of scoliosis for an additional six months, or longer, depending upon the patient's individual postoperative course.

The following representative cases will illustrate the many points discussed in this paper.

CASE 1. D. F., a twenty-three-year-old white female had had poliomyelitis for four years. Her vital capacity was 1860 milliliters (57 per cent of normal). A respirator and tracheostomy were required during the acute phase. The early bulbar paralysis had improved to a functional level but the tracheostomy continued to be necessary for an adequate airway. While the patient was fully ambulatory with good function of the trunk and extremities, excepting the poor shoulder muscles, the head was sufficiently unstable to discourage all but the simplest activities. With complete paralysis of the cervical muscles, poor capital extensors, and good capital flexors, she balanced her head by active capital flexion and gross exaggeration of all the anteroposterior postural curves, particularly the cervical lordosis. Coincident with a progressive increase in the cervical lordosis, there was a decreased tolerance to plugging the tracheostomy.

The spine was fused from the second cervical to the third thoracic vertebra with wire skeletal skull traction for three months. A felt Shanz collar and neck roll were then substituted. Due to poor cooperation about wearing the collar and strong capital flexors, the head promptly pulled into flexion with pain and some impairment of bulbar function. With applica-

FIG. 22-A

FIG. 22-B

Fig. 22-A: Case 1. Appearance of patient before surgery.
Fig. 22-B: Appearance following fusion from occiput to fourth thoracic vertebra.

FIG. 22-C

FIG. 22-D

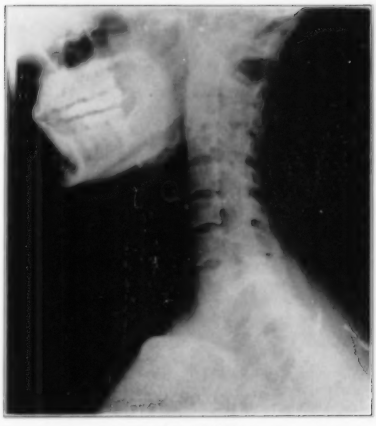

FIG. 22-E

Fig. 22-C: Preoperative position of cervical spine.

Fig. 22-D. Position following fusion from second cervical to third thoracic vertebra.

Fig. 22-E: Position following extension of fusion to skull. Note with the second immobilization the interspinous fusion mass partially absorbed. No clinical motion is evident.

tion of a corrective posterior plaster shell and a vigorous exercise program, the flexion deformity was overcome and the capital extensors increased to a grade of *fair*. However, she could not maintain the head upright throughout the day so the fusion was extended to the occiput. Halo traction was used this time (with considerably more comfort), followed by a posterior shell. The result was excellent and the patient is happy and an alert person, actively participating in social events, and attending business college. Respiratory assistance by positive pressure through the tracheostomy was used for both postoperative periods.

CASE 2. G. E., this twenty-seven-year-old white male had had poliomyelitis for three years. His vital capacity was 790 milliliters (18 per cent of normal) in the supine position, increasing to 1250 milliliters (29 per cent of normal) on sitting up. A cuirass respirator has continued to be necessary when he is recumbent. Bulbar function was temporarily impaired at the onset of his illness. His head was grossly unstable due to complete paralysis of the cervical extensors and poor cervical flexors. The capital muscles were good and the patient wore a Shanz collar, preferring partial support to the restriction of a large brace. He curtailed his activity to the minimum despite normal lower extremities and trunk and the reconstruction of functional upper extremities by bilateral flexorplasty, opponensplasty and first dorsal interosseus transfer, and an interscapular fascial transplantation.

The spine was fused from the second cervical to the third thoracic vertebra, with immobilization by a Minerva jacket as there was no positioning problem. After three months, a

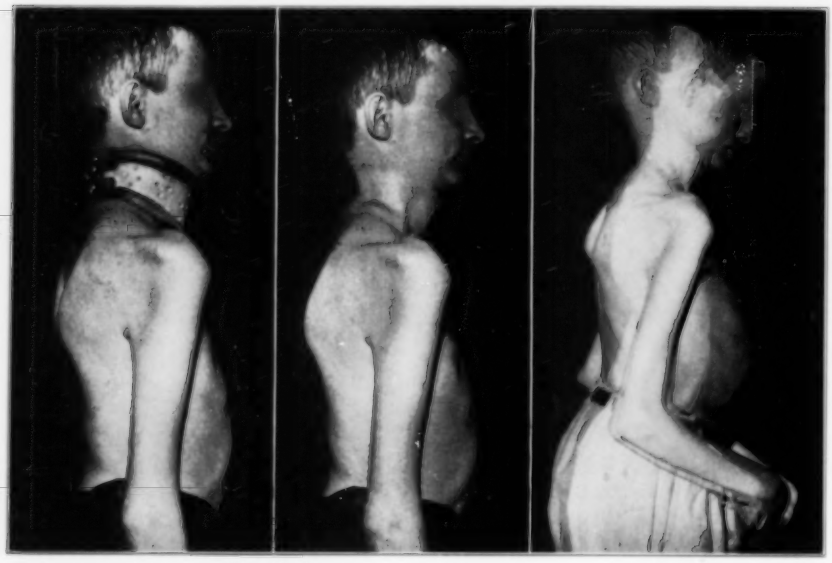

FIG. 23-A FIG. 23-B

Fig. 23-A: Case 2. Preoperative position of patient with and without Shanz collar.
Fig. 23-B: Double exposure photograph showing available neck motion after spine fusion from the second cervical to the third thoracic vertebra.

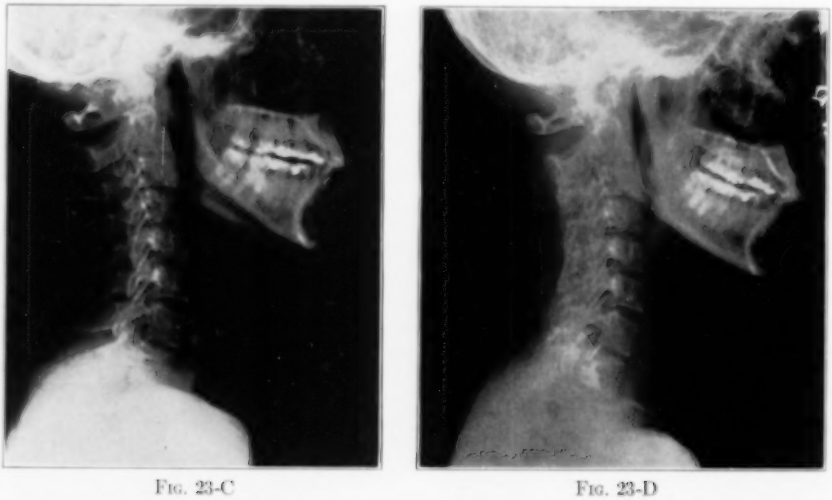

FIG. 23-C FIG. 23-D

Preoperative position. After spine fusion.

posterior plaster shell was applied. The result was excellent; his head is stable and he is now managing his own printing service.

An elective tracheostomy was performed just for this surgery so the necessary respiratory aid could be continued while he wore a full body cast. This was done by means of positive pressure through the tracheostomy.

CASE 3. K. M., a white female, eleven years old, had had poliomyelitis for one and one-half years. Her vital capacity was 300 milliliters (12 per cent) while supine, and increased to 540 milliliters (21 per cent) when she was sitting. She was independent of respiratory equipment while upright but required mechanical assistance any time she was lying. The muscles of the

FIG. 24-A

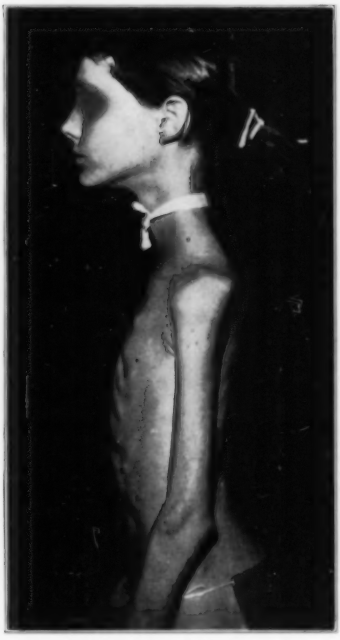

FIG. 24-B

Fig. 24-A: Case 3. Photograph showing preoperative instability of neck.
Fig. 24-B: Position one year after spine fusion.

FIG. 24-C

FIG. 24-D

Fig. 24-C: Roentgenogram showing preoperative position of neck.
Fig. 24-D: Preoperative position of spine.

FIG. 24-E

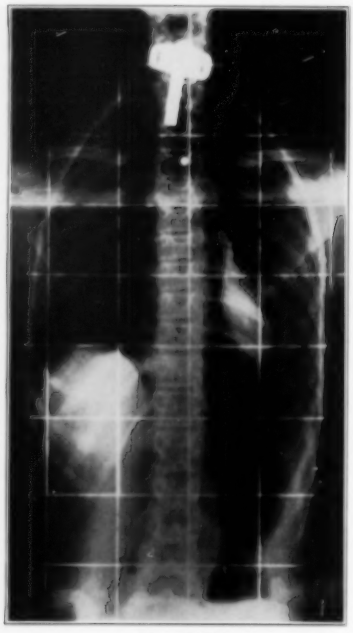

FIG. 24-F

Fig. 24-E: Postoperative position of neck.
Fig. 24-F: Postoperative position of spine after fusion from occiput through the third lumbar vertebra.

lower extremities and the abdominal muscles were good. Function in her hands, wrists, and left elbow were fair but was absent in the right elbow and both shoulders. Her neck and back were entirely paralyzed with an extremely flexible neck so that unless careful support of her head was maintained the patient was apprehensive whenever her position was changed. The patient was able to walk unassisted, wearing a body jacket and with head support.

For head and trunk stability, a spine fusion from the occiput to the fourth lumbar vertebra was done in three stages, with autogenous iliac bone being added to the suboccipital area only. Postoperative immobilization was accomplished by the halo traction apparatus for a six-month period. The patient then used a removable body jacket for an additional six months. She is now getting about without assistance, walking with confidence, and getting up and down independently.

RESULTS

To date, twenty-two cervical fusions have been performed during the past two and one-half years, of which ten have included the skull (Figs. 22-A through 22-E). Half of this latter group terminated at the third thoracic vertebra. Of the others, two extended to the tenth thoracic vertebra and the rest to the fourth lumbar vertebra to include a progressive or collapsing scoliosis. Twelve patients had adequate stability of the head so that the proximal limit of these fusions was the axis. All but two of this group had severe scoliosis associated with instability of the neck so the fusions extended to the lower thoracic or lumbar areas. Wire skeletal fixation was used in the first two patients. One patient with a simple fusion of the second cervical to third thoracic vertebra that required no special positioning used just a Minerva jacket. All the others, including all the occipital fusions, were immobilized by the halo traction apparatus. This apparatus has been used for an additional thirteen patients with high thoracic scoliosis, which will not be discussed at this time. To date we have no evidence of pseudarthrosis or loss of position.

The only complications have been in the two patients in whom we attempted to retain suboccipital motion primarily for the rotational element, despite inade-

quate muscle power. The first patient had relatively strong upper cervical flexors and promptly pulled into a fixed suboccipital flexion, with pain and increased difficulty in speech and swallowing. Correction of the position and extension of the fusion to the occiput was necessary. The other patient with a similar problem has severe bulbar weakness and associated relatively poor power in the capital flexors. As a result she has not pulled into a deformed position but when she leans forward her head falls into flexion, causing temporary obstruction of the pharynx, with resulting occlusion of the airway and interference with swallowing. These two patients demonstrate the problem of an inadequate length of fusion.

There have been no medical complications with any of the patients. We feel that the liberal use of respiratory aid during the postoperative period and judicious replacement of blood lost during surgery, as well as the protection offered by the halo traction during surgery, account for the benign postoperative course.

The vital capacities of this group of patients ranged from 8 to 50 per cent of normal. Eight of the patients were routinely dependent upon mechanical respiratory aid at the time of surgery.

We wish to emphasize the following six points:

1. The neck muscles form four functional groups: flexors and extensors of the head, and flexors and extensors of the neck.

2. Paralysis of the neck muscles may prevent the patient's taking advantage of the function that is present in his extremities.

3. Paralysis of the capital extensors may greatly embarrass or completely prevent swallowing and speech by allowing the head to fall into extreme flexion.

4. Total cervical-spine fusion is an effective way of replacing the stability essential for general activity and this fusion must include the occiput if the capital extensors are weak.

5. The halo traction apparatus is a successful means of stabilizing the head and neck for fusion in a predetermined position.

6. With the use of mechanical respiratory assistance, the presence of respiratory paralysis is no longer a deterrent to safe major reconstructive surgery.

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DISCUSSION

Dr. Edwin R. Schottstaedt, San Francisco, California: Few of us have the opportunity to work with a concentration of severely involved poliomyelitic patients suffering from head and neck paralysis, associated with problems of respiration, speech, and swallowing. However, this in no way detracts from the importance of this contribution, for the lessons learned here allow those interested and faced with such an occasional problem to face it in an optimistic and intelligent manner. I have seen some of these patients with the halo in place and those I saw were comfortable. The resultant fusions were excellent.

Those of you who have cared for the extreme functional disability arising from severe paralysis of the cervical spine will realize at once that here is a well conceived and logically executed plan of treatment. The loss of the occipital articulation is not so great a functional loss as you may think and to these patients the gain in stability and neck control is essential to rehabilitation. This technique will, I am sure, prove useful also in treatment of the difficult high cervicothoracic scoliotic curve.

The importance of the categorization of the muscle groups affecting functions in this region to capital and cervical flexors and extensors is basic to clear thinking. The realization of the effect of the position of the head and neck on swallowing and speech, coupled with a technique for solving the problem, is of extreme importance.

In our care of cervical paralysis we have usually employed the techniques of external support with brace or rigid shell. In carefully selected patients with paralyzed or weak neck flexors, we have done bilateral transpositions of the pectoralis major to replace the sternocleidomastoid muscles. We now have three such cases in our series with successful results.

It is to be expected that accidents will occasionally occur with the use of any skeletal fixation. The commonly used skeletal adjuncts to the treatment of fracture of the cervical spine also are responsible occasionally for infection and other complications. However, where one is faced with a problem of this magnitude, the possible risks involved in the use of the halo seem well worthwhile.

A further contribution made by these authors is their use of positive pressure anaesthesia and the postoperative use of the respirator.

There is one thing I would like to ask the authors to bring out if they will, and that is the age incidence of the patients they have told us about.

DR. NICKEL (closing): We feel it is safe to operate on a patient, despite his severe respiratory paralysis, with the equipment and techniques that are generally now available throughout this country. There is a general feeling that the incidence of poliomyelitis is decreasing markedly and that we don't have a lot of poliomyelitic work to do. Actually, we are facing the peak of the reconstructive work required during the next few years. Many of these are patients who have been relatively much more severely involved. There are large numbers of them throughout the country and they need the intensive care of orthopaedic surgeons.

The age incidence, generally, is late adolescence and young adulthood. We feel that this operative procedure should be done in children at an earlier age, and that there is probably no contra-indication to this, but so far we have not done it.

ADDENDUM

Since the presentation of this paper we have used the halo traction apparatus on an additional thirty-one patients with high thoracic or collapsing scoliosis. This has provided a marked improvement in both positioning and immobilization of the upper thoracic and cervical spine as compared with a Minerva jacket. The halo is now a routine part of our armamentarium for the treatment of this type of scoliosis. Only twice have we needed to remove the halo early because of recurrent pin irritation, and this only after two to three months' wear. There was no loss of correction in either case. The type of scalp most likely to cause trouble is that which is oily or redundant. The residual scar from the pin in all patients has not been more than a one-eighth of an inch dimple, which quickly fades into obscurity.

The alignment of the halo traction apparatus on the cast has been simplified by dividing the crossbar which is attached to the cast so that each upright may be adjusted individually. There have been no further alterations in technique or philosophy of management.

Degenerative Changes in the Cervical Spine

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Pain and disability of the head, neck, and upper extremity resulting from degenerative changes of the cervical spine are frequently encountered and often present a therapeutic enigma. The literature dealing with this subject presents confused and often contradictory concepts, not only of the pathology, but also of the structural anatomy.

There are certain anatomical peculiarities of the cervical spine which must be considered in order to understand fully the changes which occur. The body of a typical cervical vertebra is broader from side to side than from before backward. The superior surface has two well marked lateral lips which render it concave from side to side, while the inferior surface is notched laterally and thus is convex from side to side. The posterior surface is squared, but the anterior surface is prolonged downward to form a distinct lip. The lateral lips of the superior surfaces of the third to seventh cervical vertebrae were described as *eminentia costaria* by von Luschka, in 1858, who based his observations on Meckel's suggestion that these projections were vestigial ribs of the cervical spine. This structure has also been termed *processus lunati* by Giraudi. Rathcke noted that these lateral lips or uncinate processes develop during the second decade and that, prior to this, the superior surfaces of the bodies are flat. These processes lie in close relationship to the intervertebral foramina and are in intimate relation with the emerging nerve roots. Bovill and Drazek found that the lateral lips varied in size and extent and that some of these processes extended far enough posteriorly to present a barrier to posterolateral disc protrusions into the spinal canal. Frykholm stated that the uncinate processes are directly lateral in position in the fifth and sixth cervical vertebrae and become dorsolateral in the seventh cervical and first thoracic vertebrae; he further suggested that one of the functions served by these processes was to restrict lateral flexion of the spine in order to protect the trunk of the brachial plexus.

Some authors believe that the approximation of the lateral lips with the corresponding notched defect on the inferior aspect of the next higher body constitutes a true joint with capsule, synovial lining, and joint cavity, whereas others believe that the intervening material is the most lateral portion of the disc. It was pointed out by von Luschka that in the cervical spine the intervertebral discs do not extend as far laterally as the bodies and that the lateral lips of the cervical bodies form an articulation with the notched facet of the body above which he termed *hemiarthrosis intervertebralis lateralis.* Trolard termed these articulations *uncovertebral joints;* Brain, Knight, and Bull referred to them as *neurocentral joints,* and Jackson termed them *lateral joints.* Krogdahl and Torgerson noted the presence of a joint-like cavity bounded by a fibrous capsule and concluded that these fissures resembled an articulation and that the pathological changes and osteophytes in this area were a form of arthrosis distinct from proliferations in the remainder of the vertebral margins known as spondylosis. On the other hand, Rathcke and Güntz could find no true lateral articulations, nor could Bovill and Drazek find any joint structure in this area. Haglund concluded that a pathological condition of the lateral joints was a manifestation of disc disease and not related to a specific joint. Frykholm noted

that the lateral joints form an anchorage for the annulus fibrosus with interposed disc material. He further observed that all structures enclosed between the epiphyseal rings of two adjacent vertebrae are contained by the annulus and that the occurrence of joint-like cavities can be explained on the basis of fissuring of the annulus which is frequently seen throughout the spinal column.

The spatial relationship of the spinal cord and nerve roots to their coverings of bone were studied by Arnold and also by Elliott. At the level of the fifth cervical vertebra, the average anteroposterior diameter of the spinal canal was 1.4 centimeters; the anteroposterior diameter of the spinal cord at this level was 0.8 centimeter. The average transverse canal diameter was 2.5 centimeters; the spinal cord measured 1.3 centimeters in this plane. The nerve roots, which lie on the floor of the intervertebral foramina, fill the anteroposterior diameter and occupy approximately one-fourth of the total foraminal space, the remainder being occupied by blood vessels, lymph vessels, and areolar and fatty tissue.

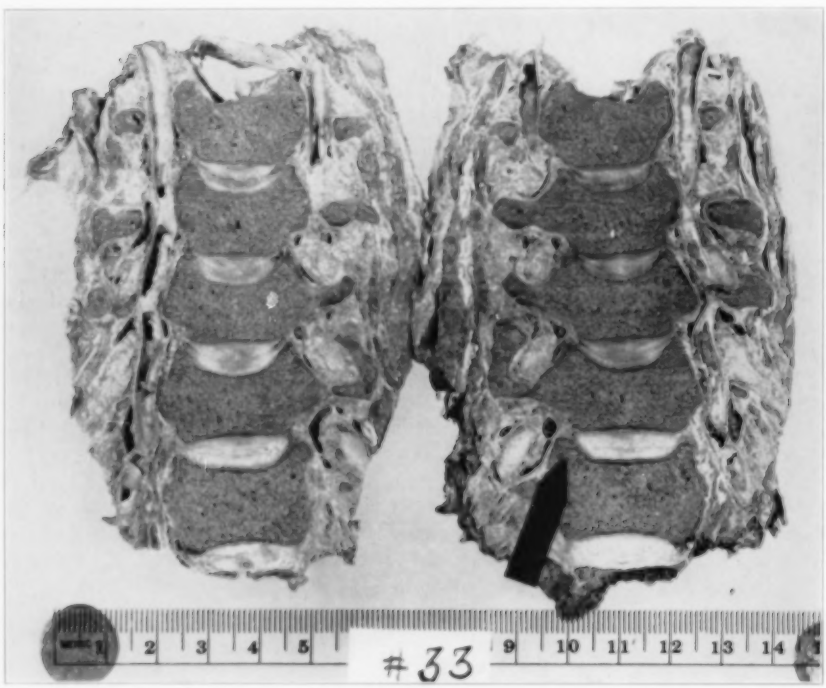

FIG. 1

A coronal section of a relatively normal cervical spine showing the relationship of the discs to the nerve roots. Arrow indicates lateral joint separating disc from nerve root.

The purpose of this study of the cervical spine is to examine the nature and the incidence of osseous and joint changes by dissection and analysis of cadaver material. In the first phase of the study, anteroposterior, lateral, and oblique roentgenograms were made of forty-one cervical spines, following which observations were made on the changes and relationships of bone, joint, disc, nerve root, and cord. In the second phase, the soft tissues were removed, and the dried vertebrae were again articulated in order to examine minutely the changes occurring in the bone structure. Twenty-seven articulated spines were available. In addition, many spines were dissected in various planes and frozen serial sections made of entire spines for the study of specific points. The average age of the specimens used in the statistical survey was sixty-eight years. There

were thirty-one males and ten females. The cause of death was known for each specimen, but no clinical history was available.

DISC DEGENERATION

The lamina of each of forty-one specimens was removed and the relationship between the spinal cord and its roots to the surrounding structures was observed. The cord and roots were then removed and each vertebra was disarticulated to note the condition of the discs and the intervertebral joints.

The intervertebral disc was considered to be grossly degenerated if it was thinned, vacuolated, and fibrillated. Most such discs showed horizontal clefts and loss of the normal elasticity. Gross degeneration was easily recognized by these means; but it was, of course, not possible to identify early disc changes by this method. Microscopic detail of the disc was distorted in preserved specimens and by the lack of proper histological fixation, and could not be evaluated. Table I shows the incidence and distribution of the gross disc changes noted.

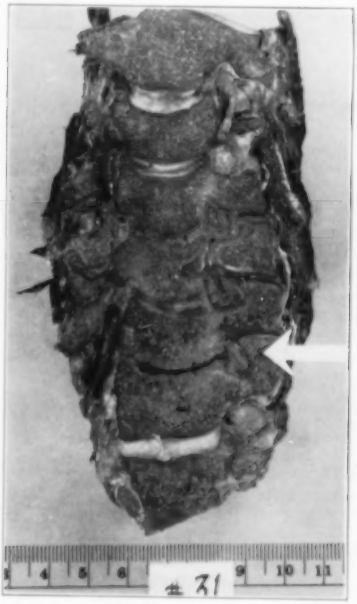

FIG. 2

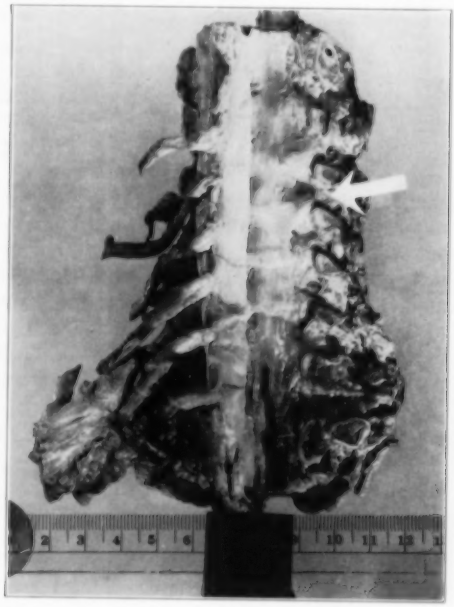

FIG. 3

Fig. 2: Coronal section of a cervical spine. Arrow indicates nerve root compressed in the foramen at the level of a degenerated disc.

Fig. 3: The spinal cord and nerve roots have been displaced to show the prominent disc levels. The arrow indicates a nodular mass of reactive bone at the entrance of the nerve foramen. Similar changes are present in the adjacent lateral joints.

Of the cervical spines examined, 49 per cent revealed disc changes between the fifth and sixth, and the sixth and seventh bodies. Degeneration was not confined to any specific area in the disc and was present in most instances in both central and peripheral portions. In five, a spontaneous interbody fusion was noted with islands of residual disc cartilage found centrally. Two such fusions occurred between each of the fifth and sixth, and sixth and seventh bodies, and one between the third and fourth body.

When the ratio of specimens showing no change at any disc level was compared with those showing changes at one or more levels and calculated for each decade from the fifth to the eighth, no significant rise was noted in the older age groups. In those spines showing degeneration of one or more discs,

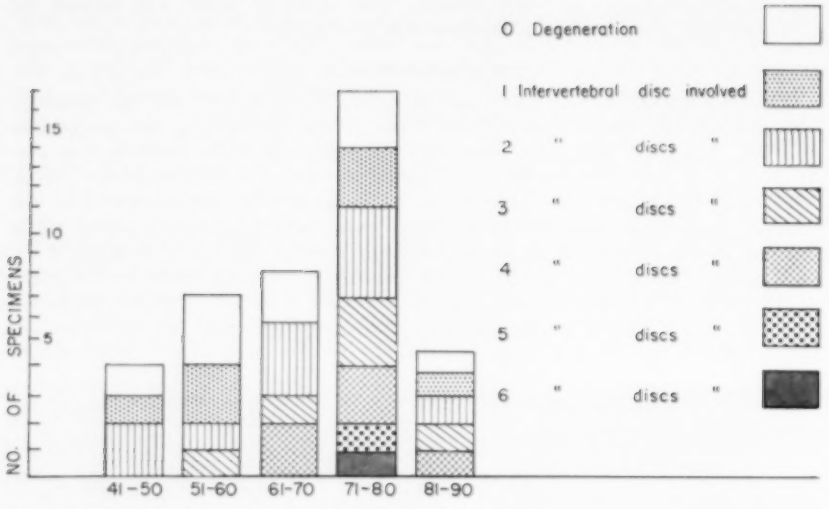

CHART I

changes at several levels were seen more frequently in the older groups. No more than two discs were involved in any single specimen below fifty years of age, whereas four or more degenerated discs were frequently seen in those above sixty years (Chart I). There were thirty-one male and ten female specimens; no significant differences could be established by division into sexes. In a study of forty spinal columns, Morton found disc degeneration at one or more levels in 70 per cent. In the present study, thirty-one of the forty-one spines (76 per cent) showed one or more disc changes.

TABLE I

DISC DEGENERATION IN FORTY-ONE SPECIMENS

C 2-3	4 (10 per cent)
C 3-4	11 (27 per cent)
C 4-5	17 (41 per cent)
C 5-6	20 (49 per cent)
C 6-7	20 (49 per cent)
C 7-T 1	5 (12 per cent)

PROTRUDED DISCS

Each disc level was investigated for nuclear material projecting into the spinal canal. Such extrusions were in all cases minute and did not lie free in the canal but were contained by the posterior longitudinal ligament. The protrusions were often directed anteriorly as well as posteriorly and did not, in the absence of reactive bone spurs, compress or displace the cord. In no case was disc material found far enough laterally to be in contact with the nerve root or foramen. Displacement of disc material was found in twelve specimens, in nine of which the entire disc showed degeneration associated with the protrusion (Table II).

POSTERIOR PROJECTING OSTEOPHYTES

Osteophytic spurs springing from the posterior surface of the vertebra and indenting the anterior surface of the spinal cord have been reported to produce

corticospinal-tract impairment. Such lesions are frequently seen roentgenographically in the oblique and lateral projections of the cervical spine and may also cause myelographic defects. In several of the specimens, projecting osteophytes produced a deep impression on the anterior surface of the cord. These spurs were largest in the mid-line; and, when two or more adjacent disc levels showed well developed spurs, a mid-line longitudinal depression on the anterior surface of the dura mater and cord was formed. Such osteophytes were always associated with disc degeneration and occasionally were seen with disc protrusions. Spur formation at the various disc levels showed a distribution pattern similar to degenerative discs (Table III).

TABLE II

DISC PROTRUSIONS

	C_2-C_3	C_3-C_4	C_4-C_5	C_5-C_6	C_6-C_7	C_7-T_1
Anterior disc protrusion with disc degeneration	0	0	1	2	1	
Posterior disc protrusion with disc degeneration	0	0	1	1		
Anterior and posterior disc protrusion with disc degeneration	0	0	1	1	1	
Posterior disc protrusion no disc degeneration	0	1	1	0	1	

TABLE III

LARGE OSTEOPHYTES PROJECTING POSTERIORLY FROM THE VERTEBRAL BODY INTO THE SPINAL CANAL (FORTY-ONE SPECIMENS)

C 2-3	0
C 3-4	1 (2 per cent)
C 4-5	7 (17 per cent)
C 5-6	11 (27 per cent)
C 6-7	7 (17 per cent)
C 7-T 1	2 (5 per cent)

Posterior projecting osteophytes were regarded as a common cause of spastic paraplegia by Pallis, Jones, and Spillane. These authors studied a group of individuals over fifty years of age who had no neurological complaints but who showed evidence of corticospinal-tract signs on careful neurological examination. These could be correlated with narrowing of the cervical spinal canal by osteophytes.

DEGENERATION OF THE LATERAL JOINTS OF LUSCHKA (UNCOVERTEBRAL JOINTS)

From the nature of this study, it was not possible to prove or disprove that these articulations are true synovial joints. The superior lateral surface of each cervical body from the third to the seventh showed a well defined blunted uncinate process directed upward in relation to the upper border of the base of the pedicle. The inferior surface of each body between the second and the sixth vertebra showed a triangular defect in relation to the lower border of the pedicle which articulated with the upward directed process of the caudad body. These so-called joints were more fully developed in the mid-cervical area, were often asymmetrical, and were usually poorly developed between the sixth and seventh cervical vertebra. In the thoracic spine, this portion of the vertebra formed the articulation between the head of the rib and the vertebral body. The cervical-nerve root at each interspace, at the point where it enters the inter-

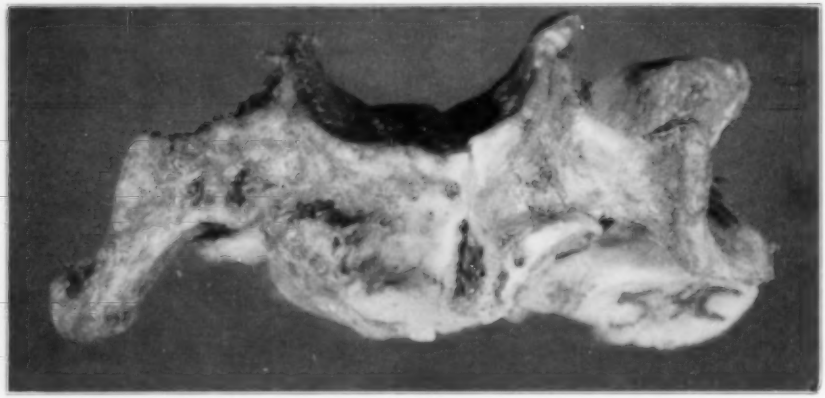

FIG. 4

The lateral lips are well seen on the superior surface of this vertebra. On the right degenerative changes have occurred.

vertebral foramen, was in close proximity to this joint. The nerve root had been reported by Frykholm to occupy one quarter to one-fifth of the diameter of the foramen. As the disc narrowed the diameters of the two structures approximated each other more closely. In anteroposterior roentgenograms of adolescents, the corresponding superior process and inferior recess of the uncovertebral joints were widely separated by the full height of the disc, but in older age groups, as the disc narrowed, the projecting uncinate process below and the recess in the body above approached one another.

TABLE IV

LUSCHKA JOINT DEGENERATION WITH PROJECTING OSTEOPHYTES IN RELATION TO ROOT (FORTY-ONE SPECIMENS)

C 2-3	3 (7 per cent)
C 3-4	9 (22 per cent)
C 4-5	15 (37 per cent)
C 5-6	21 (51 per cent)
C 6-7	16 (39 per cent)
C 7-T 1	0

Secondary changes were frequently seen in this structure. The superior process was broadened and thickened, and its cartilaginous surface showed erosion and was ringed with osteophytes. The triangular recess of the inferior aspect of the vertebra also showed cartilage erosion, and large spurs had developed which often were directed into the floor of the intervertebral foramen. These changes were seen only when the disc was markedly narrowed and degenerated. Such reactive bone formation in the Luschka joints produced a nodular mass at the entrance to the foramen over which the cervical-nerve root was displaced posteriorly just as it entered the intervertebral foramen. Although the course of the root was altered by these masses, no soft-tissue adhesions or fixation between the nerve root and the degenerated Luschka joint were noted. The incidence of these articular changes at the various intervertebral levels correlated with the levels showing disc degeneration (Table IV).

In a controlled study of 107 patients suffering with cervical and brachial pain, whose roentgenograms were compared with those from an equal number of asymptomatic individuals in the same age group, Tapiovaara demonstrated

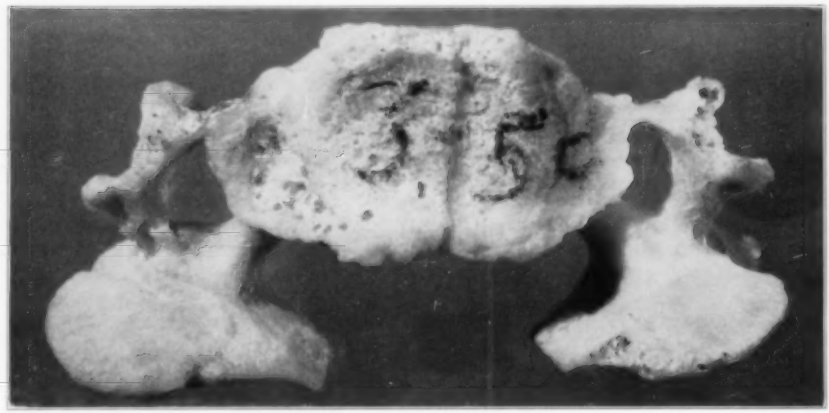

FIG. 5

The inferior surface of the fifth cervical vertebra shows advanced degenerative changes on the right partially occluding the canal of the vertebral vessels on this side.

that the only significant roentgenographic findings present in the symptomatic group were the changes in the Luschka joints and the narrowing of the intervertebral foramina.

DEGENERATION OF THE APOPHYSEAL JOINTS

The ratio of surface area of the apophyseal joint to the area of the intervertebral surface of the corresponding body diminishes in the lower cervical spine as the bodies become larger. It may be assumed that the apophyseal joints of the upper cervical spine carry a larger proportion of the weight of the head. All weight transmission between the first and second cervical vertebrae is borne

TABLE V

APOPHYSEAL JOINT DEGENERATION (FORTY-ONE SPECIMENS)

C 2-3	6 (15 per cent)
C 3-4	7 (17 per cent)
C 4-5	5 (12 per cent)
C 5-6	6 (15 per cent)
C 6-7	5 (12 per cent)
C 7-T 1	8 (19 per cent)

TABLE VI

CHANGES NOTED ON THE SUPERIOR AND INFERIOR SURFACES OF TWENTY-SEVEN CERVICAL VERTEBRAE CLEARED OF SOFT TISSUES

	Degenerative Changes Noted	Severe Degeneration
C 2	1 (4 per cent)	0
C 3	7 (25 per cent)	0
C 4	18 (68 per cent)	4 (15 per cent)
C 5	22 (81 per cent)	8 (29 per cent)
C 6	21 (78 per cent)	11 (41 per cent)
C 7	11 (41 per cent)	6 (22 per cent)

on the lateral masses which correspond to the apophyseal joints at lower levels. The most severe apophyseal joint changes were noted between the second and third vertebra. Gross changes in these joints elsewhere in the cervical spine were found to be evenly distributed. In contrast to this it should be noted that at the fifth and sixth levels there was an increased incidence of degenerative changes in the discs and in the joints of Luschka as well as a higher incidence of disc protrusions and of osteophytoses on the bodies (Table V).

Degeneration was most pronounced at the periphery of the joint where spurs on the superior facet partially enclosed and encircled the inferior facet, making separation of the joint surfaces difficult. The osteophytosis, even in the most severe cases, was located so far posterior to the intervertebral foramen that no narrowing of the foramen or contact with the root could be demonstrated.

EXAMINATION OF CERVICAL SPINES CLEARED OF SOFT TISSUES

In twenty-seven specimens, all of the soft tissue was removed by heating in an alkaline solution and the fat was removed from the dried bones by immersion in ether following which the vertebrae were articulated and studied. The superior and inferior surfaces of each body were examined for irregularities and roughening, as well as for the presence of osteophytes. Particular attention was directed to joints of Luschka, as well as to the apophyseal joints and to the vertebral vessel foramina in the transverse processes.

Degeneration of the inferior surface of a body was always matched by a degeneration of similar magnitude of the superior surface of the body below. The distribution of changes recorded from the examination of the cleaned bone closely correlates with the degenerative findings seen in the intervening disc (Table VI). One hundred and thirty-five paired vertebrae were examined for degeneration of their contiguous disc surfaces, and it was possible to compare these observations with the changes in the intervening disc fibrocartilage previously noted. In 100 joints (74 per cent), a correlation existed between disc degeneration and bone degeneration on the surface of the body in contact with the disc. In twenty-seven (20 per cent) of the joints studied, bone changes were seen without disc degeneration, while in eight (6 per cent), changes were seen in the disc without bone changes.

Each vertebral body was examined for osteophytes projecting posteriorly into the spinal cord which might significantly narrow the anteroposterior diameter of the canal. The average anteroposterior diameter of the spinal canal at the level of the fifth cervical vertebra was found to be 1.4 centimeters, while the diameter of the spinal cord at this level was 0.8 centimeter. Only those spines which presented a projection of more than two millimeters were recorded and nine such spines were found. In five of the nine, the projection was in the fifth and sixth cervical vertebrae.

Roughening and enlargement of the lateral joints of Luschka and changes in the intervertebral body surfaces were observed to occur coincidentally. Twenty-two (82 per cent) of the specimens showed such changes in the fifth cervical vertebra. Nineteen of these had changes both in the lateral joints and in the surface of the intervertebral body.

An interesting observation was the broadening of these lateral joint surfaces in a lateral direction by osteophytic reactive bone formation. The resulting bone projections partially occluded the adjacent vertebral vessel foramen in the transverse process. This encroachment always resulted from changes on the inferior recessed surface of the superior body and not from the projecting uncinate process on the vertebra below. Normally, the plane of the Luschka joint is perpendicular, but as changes develop it becomes oblique and occasionally horizontal. It is this change of plane and the broadening of the joint which causes the lateral extension of the joint margin to the base of the transverse process and to the vertebral foramen. This was observed bilaterally in twenty verte-

brae, and in five instances the osteophytes were large and appreciably occluded the canal. This phenomenon was noted most often in the fifth cervical vertebra.

CORRELATION BETWEEN ROENTGENOGRAPHIC AND ANATOMICAL FINDINGS

In forty-one specimens with roentgenograms in the anteroposterior, lateral, and oblique projection which were later dissected, a correlation between the roentgenographic and anatomical manifestations of disc degeneration was found in 67 per cent. Narrowing of the intervertebral space was the most common roentgenographic finding. Even minor narrowing of the interspace was shown to be indicative of disc degeneration. In the presence of marked narrowing of the intervertebral space, the bodies of the adjacent vertebrae were frequently seen to be decreased in height. It was unusual to find other abnormal roentgenographic findings in the absence of a degenerated disc. Anterior lipping of the body was also a common finding, being present in 25 per cent of the vertebrae examined. A concavity on the surface of the spur contiguous to the interspace frequently revealed anterior disc protrusion. Posterior spurs were most easily seen in the oblique roentgenograms. Always associated with a narrow disc space, they were present roentgenographically in sixteen of the twenty-eight vertebrae on which large posterior osteophytes were found on dissection. As expected, most of these occurred between the fifth and seventh cervical vertebrae and the majority of these spurs arose from the area of the lateral joints which also showed degenerative changes.

The incidence of roentgenographic changes in the lateral joints was also correlated with the incidence of the changes found by dissection. Sixty-four interspaces showed changes on dissection and fifty-three of these showed roentgenographic changes (83 per cent). Roentgenographic examination of the apophyseal joints is difficult but changes were best seen in the lateral view. There was a poor correlation between the changes seen roentgenographically and the results from dissection of the apophyseal joints. In only twelve of the thirty-seven joints with anatomical changes were the changes diagnosed by roentgenograms (32 per cent).

COMMENT

The fifth and sixth cervical discs are subjected apparently to forces which result in more degeneration and loss of disc substance than the other disc spaces in the cervical column. Disc protrusions accompanied by varying amounts of reactive bone formation were observed but no frank herniations of a disc were encountered in this age group (average age, sixty-eight years). Degenerative changes occur in the majority of individuals reaching the sixth decade. While cervical pain and brachialgia are not uncommon in this age period, the incidence of these symptoms certainly does not correspond to the high incidence of pathological changes demonstrated by roentgenograms or gross examination of the cervical column.

An intervertebral space which is profoundly involved shows a characteristic pattern of pathological changes which involve the entire disc space. Prominent in this pattern are circumferential reactive bone changes at the margins of the bodies which abut on the involved disc space. These changes also involve the area of Luschka's joints laterally. In contrast to this the apophyseal joints frequently escape involvement. As a matter of fact a frequent observation in this study was that severe degeneration of the apophyseal joint occurred in the presence of a normal disc space. This would indicate that an independent mechanism is at work here.

In this study, particular attention was focused on the spatial relationships of disc alteration and consequent reactive bone formation to the nerve roots and the spinal cord. Particular emphasis is placed on the importance of the bone changes in the joints of Luschka due to this frequent occurrence and their

location close to the emerging nerve roots. Spur formation here beneath the nerve root just as the nerve enters the intervertebral foramen would seem to be an important mechanism in the production of radiating pain. The projecting osteophytes from the posterior surface of the body observed in these specimens were frequently large enough to groove the overlying dura mater and cord. After removal of the cord from the spinal canal, the level of each intervertebral disc often remained imprinted on the cord and could be clearly identified. These posterior spurs would also appear to be key factors in the production of symptoms. Reactive bone changes on the lateral margins of the inferior surfaces of the vertebral bodies in the region of the Luschka joints were observed, when extensive, to encroach upon the foramina for the vertebral vessels. The possibility of reduced blood flow or arterial spasm in the vertebral artery as a result of these bone changes should be considered. This merits further investigation.

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(Continued on page 102)

Severe Compression Injuries of the Hand in Industry

Amputation *Versus* Rehabilitation *

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The term *compression injury* is applied to a variety of industrial injuries of the hand caused by power presses, rotating cylinders, and similar machines. These injuries are characterized by severe tissue damage both in area and in depth. Similar injuries can be found in the literature under such names as wringer injuries, deep burns, and many others [1, 3]. Such trauma combines the effect of thermal burns with that of severe compression. The latter alone has a severely destructive necrotizing effect. It also compounds and intensifies the effect of the heat. Some of the injuries may include the elements of avulsive and crushing trauma.

In the many instances the patient is advised to have the extremity amputated (Fig.1). Rehabilitation of these injured hands often is undertaken in spite of the skepticism of the referring surgeon. The following report reviews a group of about twenty-five patients with compression injuries so treated in the past few years.

Fig. 1

Passive policy of "waiting until the hand is ready for skin-grafting." Three and a half months after injury, necrotic tissue supports massive purulent drainage which contributes to devitalization of the exposed structures. The wound is indolent and shows no tendency to granulate or epithelize. Drilling holes in the denuded bones at this stage introduces infection into the marrow. This hand was amputated. Note that the thumb and volar surface of the hand, except for fingers, are intact.

While a few of the hands were seen immediately after the injury, the majority of the patients were referred to me after a prolonged delay, varying from a few weeks to several months. The reason for this delay was that as long as the wound was covered by an eschar, the extent and severity of the injury was not apparent; it was looked upon as a conventional burn and the treatment was "waiting until the wound becomes ready for the skin-grafting." Normally, eschar begins separating in the third week but massive eschars, involving avascular tissues, separate slowly; frequently they are still adherent two months after the injury. By that time a severe infection may be established beneath the eschar, devitalizing the surrounding tissue which may have escaped destruction.

The common characteristic of all these compression injuries was massive

* Read at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., January 31, 1958.

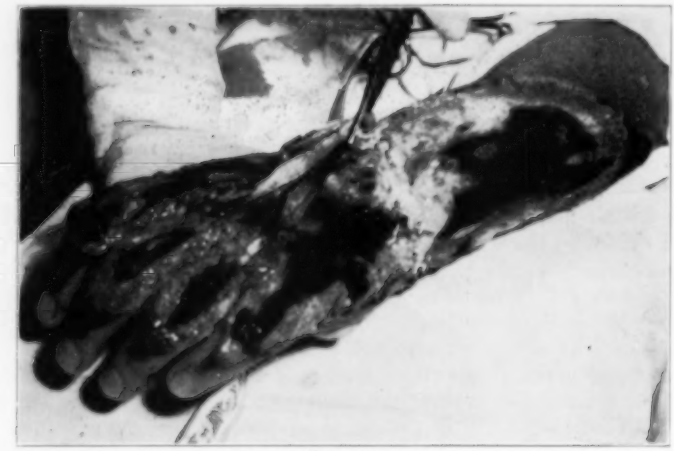

FIG. 2-A

Figs. 2-A through 2-I: Typical case of compression burn of the dorsum of the hand.

Fig. 2-A: Excision of eschar three weeks after injury.

FIG. 2-B

Result of primary débridement.

necrosis of the soft tissues. The bone, if it escaped fracture and comminution, proved itself quite resistant to compression and heat. Its damage was usually limited to devitalization of the cortical layer, which was caused not necessarily by trauma, but by prolonged exposure and impaired blood supply. The injury to the joints was due primarily to necrosis of the periarticular structures, exposure of the joint cavities, and secondary destruction of the cartilaginous joint surfaces.

The phalangeal joints were most frequently involved in these injuries, and ankylosis of these joints was the most consistent final disability. The metacarpophalangeal and the wrist joints, being better protected, often escaped injury. The surface involvement varied greatly. In a number of patients the main damage was localized to the fingers and the distal part of the hand; in others, the injury extended to the elbow. In many instances, lacerations or superficial burns were present adjacent to the main area of injury.

Fortunately, over 80 per cent of the injuries involved the dorsal surface. Since the essential neurovascular supply of the hand is located on the volar surface, there are potentialities for restoration even after the most destructive dor-

sal injuries. By protecting the surviving structures, by keeping them in functional alignment, and by substitution of skin and tendons, it was possible to restore serviceable function. In similar injuries on the volar side circulatory impairment, damage to the important nerves, and destruction of the crowded palmar compartment were likely to result in a painful, frozen, anaesthetic hand.

In most of the dorsal injuries the thumb escaped the brunt of the trauma. It always merited special attention, and in some instances the entire rehabilitation program was planned around the functional unit of a thumb and one finger.

REHABILITATIVE PROGRAM

The rehabilitative program may be divided into the following consecutive phases, though they frequently overlap each other: débridement, temporary resurfacing and control of infection, definitive resurfacing, functional alignment, mobilization, and kinetic replacement.

Débridement and Temporary Resurfacing

In most cases the time of débridement was governed by how soon after injury

FIG. 2-C

After first skin-grafting.

FIG. 2-D

Note functional position of hand. Some metacarpals, phalanges, and a fragment of the ulna are still exposed and are treated by drilling and decortication before the temporary resurfacing is completed.

FIG. 2-E
Resurfacing with an abdominal flap.

FIG. 2-F
Abdominal flap covering fingers, mitten fashion.

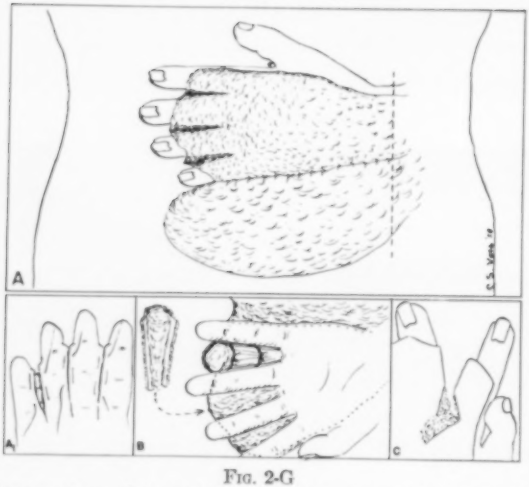

FIG. 2-G
A, Diagram of resurfacing of fingers with single flap: A_1, fusion of fingers on volar surface and application of dorsal flap, mitten fashion; *B*, alternate procedure of lining the undersurface of the flap with skin grafts; *C*, separation of fingers and reconstruction of web.

the patient was seen and was performed much later than was desirable. When a firm eschar was present débridement was performed preferably during the second week [1]. This delay facilitated the differentiation between viable and devitalized tissue and reduced the inflammatory reaction. When adequate débridement could be performed and the wound was free of necrotic material and infection, definitive resurfacing with a flap was performed either immediately or after a few days' delay [2]. However, in the majority of cases débridement was incomplete because it was not possible to eradicate all the necrotic foci without causing additional injury. In such cases the immediate aim was to obtain a temporary epithelial cover as rapidly as possible, thus minimizing the secondary damage by infection and exposure (Figs. 2-A through 2-D).

Split grafts could always be obtained in unlimited quantity without causing any serious disability. They were used at the time of the first débridement but adhered only wherever a vascular base was present. If purulent infection was present underneath the eschar, the skin-grafting was delayed a few days and the wound prepared with wet dressing. The grafts did not interfere with adequate

FIG. 2-H

Figs. 2-H and 2-I: Final result after separation of fingers and after multiple tendon grafts from foot to substitute for extensors.

FIG. 2-I

drainage and usually reduced the wound to a fraction of its original size. Additional débridements were carried out either as separate procedures or during the dressings, and as soon as areas of granulation appeared they were immediately covered with split grafts. (It was routine practice to refrigerate the excess of skin grafts after each operation, so that they were available when needed). Thus, in a few weeks after the initiation of treatment, the entire wound consisted of islands of denuded bone and exposed joints.

The phalangeal joints usually were promptly obliterated. However, the larger

FIG. 3-A

Figs. 3-A and 3-B: Example of primary resurfacing with a flap. Lacerations on palmar surface were repaired on admission.

Fig. 3-A: Excision of eschar ten days after injury. Dorsal aponeurosis is destroyed and phalangeal joints exposed.

FIG. 3-B

Primary flap on dorsum of hand. Fingers were separated in subsequent stages.

FIG. 4-A

Figs 4-A through 4-E: The hazards of primary resurfacing.
Fig. 4-A: Débridement and flap-resurfacing was performed thirty days after injury.

joints (the metacarpophalangeal or particularly the radiocarpal articulation) formed deep pockets from which necrosis and infection had to be eradicated before the cavities filled in with granulation tissue. To accomplish this these pockets were lightly packed and the extremity was splinted in plaster, maintaining the functional position. At this stage the drainage was slight and the dressings were changed at infrequent intervals. It required more than one month for these joints to become obliterated. Subsequently a firm, painless, fibrous ankylosis formed.

The exposed bone was treated by drilling multiple holes through the cortex, thus allowing buds of granulation to sprout from the marrow. Such drilling was usually delayed until the surrounding areas were epithelized and the wound was

FIG. 4-B

Purulent arthritis of metacarpophalangeal joints of index and long fingers; osteomyelitis of the latter resulted in abscess formation and partial loss of flap. The long finger was sacrificed but its skin utilized to supplement the flap. Note adduction contracture of thumb.

FIG. 4-C

Destruction and ankylosis of index metacarpophalangeal joint. Angulation of middle phalanx of ring finger corrected by osteotomy.

free from drainage. Additional holes were drilled if necessary, or the cortical bone between the islands of granulation was removed with rongeurs. Wet dressings were helpful in stimulating the granulation in preparation for the split grafts which would complete the temporary resurfacing.

Spontaneous sequestration of the exposed cortical bone could last several months. Decorticating the bone more rapidly by using an osteotome or power saw was tried but abandoned because these instruments caused too much additional trauma. Because of its superficial position, the distal part of the ulna was frequently exposed and subluxated. It was usually resected since its blood supply was poor and it was not essential for satisfactory function.

The preceding treatment did not require continuous hospitalization. Many of the dressings and minor procedures could be carried out in the office, with short readmissions to the hospital when needed.

Definitive Resurfacing

Practically all these cases required resurfacing with a flap with a substantial subcutaneous pad in order to supply a stable tegumental cover, to allow revascularization of the damaged bone, to make possible an operative approach to deep structures at a later date, and to fill in the contoural defect.

Primary application of a flap to an open wound carries the advantage of a tremendous saving in time, hospitalization, and number of operative procedures. It may be compared with delayed closure of a wound, and it is safe as long as the wound is free of infection and necrotic material, and the surrounding skin is intact (Figs. 3-A and 3-B). A hazard of primary flaps is the possibility that a focus of infection centered around some devitalized tissue, often within a joint cavity, may be overlooked; this leads to osteomyelitis and abscess formation underneath the flap (Figs. 4-A through 4-E).

In the majority of the cases flap-resurfacing followed the temporary one of split-grafting. The split grafts were excised or scraped from the bone to which they adhered. All flaps used in this group (except one) were direct abdominal

flaps, undelayed, up to twelve inches in length and five inches in width (Figs. 2-E and 2-F). The broad pedicle, corresponding to the length of the flap, assured the blood supply. To avoid any open wound, skin grafts were applied to the donor surface on the abdomen as well as the undersurface of the pedicle. A tubed thoraco-epigastric flap was used in one case (Figs. 5-A through 5-E) but it required several stages of preparation and transfer. Untubed flaps could be handled more simply and faster, with greater economy of tissue and fewer operative stages.

FIG. 4-D

Figs. 4-D and 4-E: Final result. Adduction contracture corrected with split graft.

FIG. 4-E

In order to utilize a single flap for the hand and the fingers the technique depicted on the diagram (Fig. 2-G) was utilized. When skin was present on the lateral surface of the adjacent fingers it was dissected, forming narrow flaps which were reflected volarward and sutured together, fusing the digits. In this manner a continuous raw surface was obtained to serve as a bed for a single abdominal flap. When the lateral surfaces of the fingers were destroyed, this procedure could not be used. The abdominal flap was then placed over the fingers, which were held

FIG. 5-A

Compression burn of dorsal surface similar to that of Fig. 2-A three months after initiation of treatment. Wrist joint and metacarpophalangeal joints of long, ring, and little fingers are obliterated with granulations. Skin-grafting was done on the wound except for denuded metacarpals, phalanges, and distal portion of the ulna. Drill holes and islands of granulation are apparent in exposed bone.

in abduction, and small stents with skin grafts were inserted between the fingers, in contact with the undersurface of the flap. This technique was much less effective and did not prevent some shrinking of the abdominal flap. The defatting of the flap over the fingers was performed in subsequent operations when the fingers were separated and the webs reconstructed. No matter how generous the abdominal flaps were, additional free skin grafts were needed at this stage.

Functional Realignment

Careful splinting in a functional position was maintained throughout the entire treatment. The injured joints were immobilized in the desired position, so that by the time the resurfacing was completed there was present either an osseous

FIG. 5-B

Thoraco-epigastric skin tube to be transferred, in stages, to hand and forearm. The fifth ray was ablated and distal end of the ulna excised.

FIG. 5-C

Diagram showing tendon transfer to activate thumb-index unit. Palmaris longus and two sublimis flexors are substituted for extensors and abductor longus.

or a firm fibrous ankylosis. However, in many instances digital fragments were originally so distorted that it was necessary to improve their alignment. After the flap was in place and the severe osteoporosis improved, the necessary osteotomy or arthrodesis could be carried out in conjunction with the revision of the flaps. The immobilization of fragments was obtained by transosseous pin fixation.

In order to maintain maximum mobility of the thumb, special attention was paid to the first interdigital space. Adduction contracture of the thumb was frequently present. It was not only of cutaneous origin but combined with myogenic contracture of the fibrosed adductors. The correction of these contractures called for excision of the scar tissue and fibrosed muscle and skin substitution. In the majority of cases a full thickness or split graft was adequate in this location and preferable to the more involved application of a flap (Figs. 2-H and 4-D).

Mobilization

As soon as feasible, passive and active exercises were started to limber the preserved joints and to strengthen the remaining musculature. Dynamic splinting of various kinds was substituted for the static splinting employed during the acute phase. Capsulectomy of metacarpophalangeal joints was often performed to increase the range of flexion. This too was sometimes combined with the division or defatting of the flap on the fingers. At this stage the patient was encouraged to continue his exercises at home, to use his hand as much as possible, and to return to work.

Kinetic Replacement

A period of two to six months was allowed to elapse before kinetic replacement was considered. It consisted of replacement of the missing extensor tendons of the wrist and fingers and occasionally in improvement of opposition in injuries of the thenar area. Free tendon grafts were used to replace the missing extensor tendons, including the abductor of the thumb. When no tendon stumps were left in the forearm, the proximal insertion of the tendon grafts was made by weaving them into the muscle mass (Figs. 2-A and 2-I). When the entire dorsal musculature

on the forearm was destroyed, tendon transfers were used from the volar side (Figs. 5-C through 5-E).

FIG. 5-D
Final result.

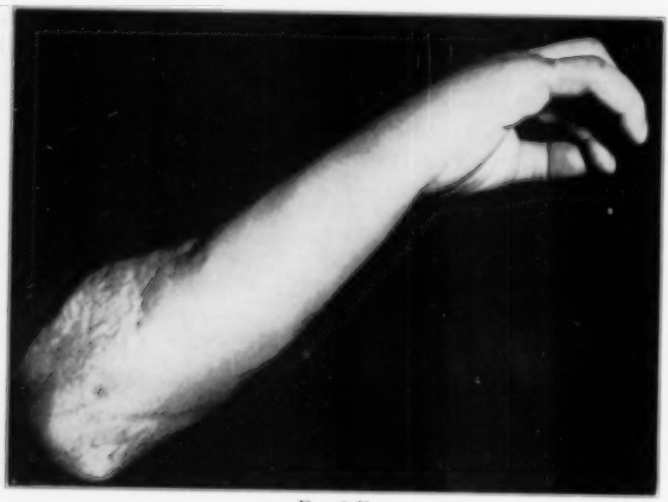

FIG. 5-E
Final result.

INJURIES OF THE PALMAR AND VOLAR SURFACES

While the foregoing discussion refers primarily to dorsal injuries, the same principles apply to volar injuries. However, palmar and volar injuries have had a poor rehabilitative prognosis. Digital anaesthesia, with or without circulatory impairment of finger tips, is always an indication that there is an extensive involvement in depth and that it has penetrated the plane of tendons and neurovascular bundles (Figs. 6-A and 6-B). I had thought that nerves known to be resistant to infection might eventually show some signs of recovery. Effective and early débridement in this location was not performed, since it would be impossible to protect the neurovascular bundles within the necrotic mass. Thus, it took several weeks before even temporary resurfacing could be accomplished.

In none of the cases did the anaesthesia, once established, show any signs of subsequent improvement. Possibly the surrounding ischaemic scars strangulating the nerves prevented any potential recovery and contributed to the final degeneration. Such a mechanism was suggested in one patient where the avulsive type of injury permitted the inspection of the nerves of the forearm immediately after the injury. In spite of anaesthesia of the fingers, the nerves were not disrupted and were of normal appearance. When the amputated forearm was dissected several months later, both nerves were reduced to thin fibrous bands (Figs. 7-A through 7-C).

In cases of massive necrosis of the palm with destruction of flexor tendons, a less ambitious rehabilitative program focused on the most salvageable part of

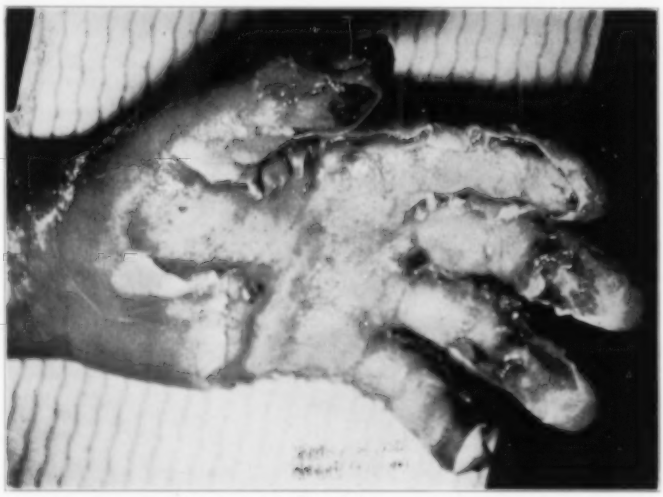

FIG. 6-A

Figs. 6-A and 6-B: Compression burn of the palm.
Fig. 6-A: Discoloration and anaesthesia of all digits.

FIG. 6-B

Flap was used after prolonged treatment. Replacement of tendons are not indicated in completely anaesthetic hand. The absence of sensory and kinetic function makes rehabilitative prognosis poor.

FIG. 7-A

Compression injury of forearm and palm with avulsion and multiple fractures. Neither volar tendons nor major nerves are severed.

FIG. 7-B

Result of temporary resurfacing. Hand is frozen, anaesthetic, and painful (probably due to vascular insufficiency).

the hand was the more realistic approach. In one patient the maximum rehabilitation was accomplished in two simple procedures, taking advantage of the intact thumb (Figs. 8-A and 8-B). Nothing would have been gained by trying to preserve the full length of the fingers nor in resurfacing with an abdominal flap; the fingers would have remained anaesthetic, frozen, and probably painful. The free grafts on the palm and on the fingers were quite adequate to permit limited use of the hand. The flaps of the dorsal skin wrapped around the tips of the stumps provided better padding and sensation.

SUMMARY

Industrial hand injuries consisting of massive necrosis of soft tissue with exposure of the bones and joints are among the most severe encountered in civilian practice. Salvaging and rehabilitating these extremities requires aggressive, pur-

poseful treatment. It is aimed at preserving all salvageable structures, maintaining functional position, and restoring as much motion as possible by mobilization of joints and tendon substitution.

These cases differed so much in area and depth of involvement and in associated damage that comparative evaluation and statistical analysis is of little

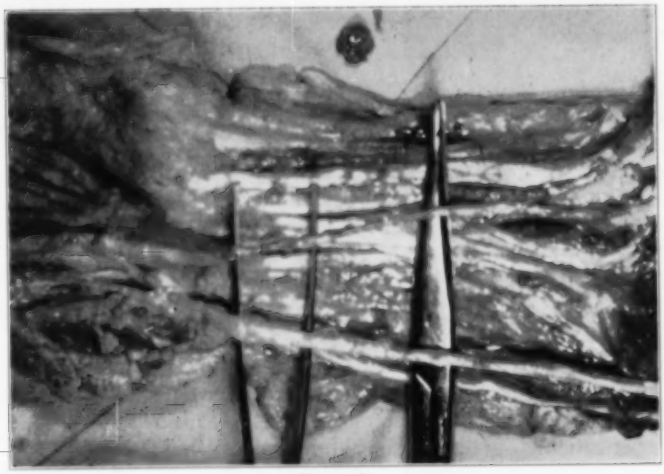

FIG. 7-C

Amputation specimen. All tendons are encased in scar. Note thinness of ulnar and particularly of median nerve in the distal part of the forearm. Nerve fibrils were replaced by fibrous tissue.

FIG. 8-A

Figs. 8-A and 8-B: Compression burn of palm, fingers, and dorsum of hand, similar to that of Fig. 6, except for intact thumb which has normal sensation and musculature. Final result after two operations: débridement with partial amputation of fingers, followed by skin-grafting. Secondary skin-grafting was done at base of palm and across first digital web to restore maximum abduction and mobility of thumb, combined with angulation osteotomy of distal phalanx of index finger. Note flaps of dorsal skin covering tips of finger stumps.

FIG. 8-B

value. However, observing these patients several years later, there could be no doubt that the rehabilitative effort was thoroughly justified.

The permanent disability in dorsal injuries consisted of limitation of function of the joint and reduced strength. A serviceable grasp and pinch mechanism was established in all cases.

Palmar and volar injuries have a poorer rehabilitative prognosis. Structural restoration of the hand is of little value unless there will be serviceable sensation and function. Damage to the neurovascular supply was responsible for the only amputation performed in this group.

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DISCUSSION

DR. HANS MAY, PHILADELPHIA, PENNSYLVANIA: This is a wonderful demonstration of the reconstruction of severe crushing injuries of the hand. Dr. Lewin, however, states that in transplanting one single dorsal flap to the fingers, the fingers tend to contract in adduction. I have found it quite helpful in these cases to use two types of flap, one to cover the dorsal surface of the hand and a pocket flap to close the dorsum of the fingers. These flaps keep the fingers abducted.

DR. J. EDWARD FLYNN, BOSTON, MASSACHUSETTS. I have a question to ask Dr. Lewin. How would you treat extensive avulsion wounds over the volar and dorsal aspects of the hand when skin, subcutaneous fat, and fascia have been completely avulsed?

DR. JOHN L. BELL, CHICAGO, ILLINOIS: As Dr. Lewin pointed out, it is not always possible to perform a complete primary excision of devitalized tissue in the severe compression injury of the hand in which the tissues are concomitantly burned. The excision may have to be performed in several stages because of the inherent difficulty in determining accurately the depth of the burned tissue. We have not performed multiple drilling of the cortex of exposed bone in order to prepare this surface for skin coverage. Usually when we encountered burned bone we removed the devitalized bone by means of a small chisel. As Dr. Lewin emphasized, bone should be covered as early as possible.

DR. LEWIN (closing): Dr. May suggested the use of pocket flaps to keep the fingers in abduction. Personally I do not like pocket flaps; they are difficult to handle during the

postoperative period. When one side of the hand is covered with skin and lies against the raw donor area there is a great deal of maceration which can result in infection. This may be avoided by gluing a skin graft with rubber cement against the side of the hand in contact with the donor area. In general, I would prefer open flaps. However, Dr. May's suggestion may be practical in some instances.

Regarding Dr. Bell's comments on débridement of bone, I have abandoned the use of osteotomes to decorticate small bones like metacarpals and phalanges. It requires considerable force to remove the hard bone and when a large surface is denuded, the entire bone tends to separate from its bed.

Dr. Flynn asked about avulsion injury on both sides of the hand. I am treating a patient with a similar injury at the present time. The skin is avulsed from the dorsal and palmar surface up to the wrist. The only remaining island of skin on the hand is over the proximal and distal phalanges of the thumb. The injured hand was debrided a few days ago and most of the fingers had to be amputated. Since the palmar surface is more important, it is desirable to get flap coverage for it. My plan is to place the hand in a pocket in the laterodorsal region so that the palm lies against the skin flap. The dorsal surface can be resurfaced later with split-skin grafts.

Experiences with a Finger-Joint Prosthesis*

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Reconstruction of stiff and painful finger joints presents difficult problems, and a completely satisfactory surgical solution is still wanting. Severe injuries involving the metacarpophalangeal and interphalangeal joints often result in complete destruction of the joint with residual deformity and pain. Functionally, these fingers may be useless and frequently amputation is the only recourse.

Numerous surgical procedures have been performed in attempting to correct this condition. However, the results of capsulectomy, arthroplasty, and arthrodesis are not always spectacular and may leave much to be desired. Capsulotomy [1], with excision of the collateral ligaments, may give satisfactory results when there is no intra-articular involvement; more favorable results may be expected in the metacarpophalangeal joints than in the interphalangeal joints. In cases with joint damage, Bunnell emphasized that the results of arthroplasty are best in the metacarpophalangeal joints and less satisfactory in the interphalangeal joints because of the problem of lateral instability. He favored arthrodesis of the proximal interphalangeal joint in moderate flexion.

Such arthroplastic procedures as the placing of a metal cap [3] in the interphalangeal joint or resection of the distal portion of the proximal phalanx may produce a satisfactory range of motion; however, there remains the problem of insufficient lateral control. Graham described the replacement of faulty articulations with half-joint transplants and whole-joint transplants. He felt that joint transplantations to the hand could be successful because the bones are small and may be adequately nourished, thus avoiding necrosis. However, there is still the

* Read at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., February 1, 1958.

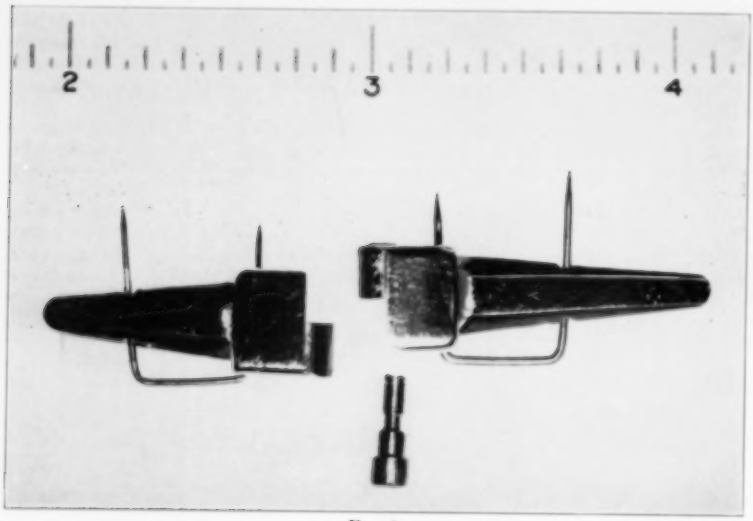

FIG. 1

Metal hinge-joint finger prosthesis, disassembled, with its component parts.

FIG. 2

Instruments especially made to facilitate the insertion of the prosthesis.

FIG. 3

Photograph of titanium prosthesis after insertion in proximal interphalangeal joint of long finger. Note staples in both phalanges.

possibility of absorption of the transplanted articular surfaces which would result in angulation and dislocation.

The purpose of this report is to describe a method of replacing the proximal interphalangeal and metacarpophalangeal joints of the index, long, and ring fingers. The results obtained by this method have been encouraging although not entirely satisfactory. By using this procedure it has been possible to avoid arthrodesis of the involved joints or amputation of a stiff but otherwise normal finger. Digital injuries, severe enough to require replacement, are common in military personnel. The development of this prosthesis represents an effort to find a more satisfactory solution in taking care of this common problem. To date our experience with this device has been limited to fourteen patients treated during a period of thirty-nine months.

THE PROSTHESIS

The prosthesis is a replica of the normal joint and replaces the entire joint. It was initially constructed for us of stainless steel, by a German surgical instrument company, from our wooden model and sketches. Since submitting the original design, several modifications and improvements have been made in conjunction with an American manufacturing concern.

The device is now fabricated of titanium. It consists of two parts joined by a simple hinge-joint which is locked by a half-threaded rivet screw, and each part has an intramedullary stem for insertion into the bones of the finger (Fig. 1). The intramedullary stem is triangular in shape and designed to prevent rotation of the finger after insertion. The hinge-joint portion is finely beveled to prevent catching or irritation of soft tissue during movement through an arc of 100 degrees. A recent addition is the placement of a staple through each hub and stem portion to prevent sinking of the prosthesis into the phalanx after bone resorption occurs.

A standard-size prosthesis was developed for use in the proximal interphalangeal joint of the finger. This size and shape was determined after studies on cadavera and measurements of the average adult-hand bones. The dimensions are: over-all length, fifty millimeters; length of proximal medullary stem, twenty-two millimeters; length of distal medullary stem, sixteen millimeters; length of hub (including hinge-joint), twelve millimeters; width of hub, eight millimeters; and depth of hub, three to four millimeters. However, for individual selection a larger or small size can be constructed. A larger but similar prosthesis can be employed to replace a metacarpophalangeal joint.

Special instruments were constructed to facilitate the insertion of the device

FIG. 4-A

Case 9. Roentgenograms showing disruption of proximal interphalangeal joint secondary to old fracture-dislocation.

(Fig. 2). These include phalangeal retractors, phalangeal bone holders, intramedullary reamers, chisels, screwdrivers, a prosthesis impactor, and a swaging instrument to lock the rivet screw, all of which have proved useful.

INDICATIONS

The prosthesis was designed to replace an irreparably damaged proximal interphalangeal joint whereby the finger had been rendered stiff and useless (Fig. 3). Usually, there is residual deformity with the finger ankylosed in malposition. The time interval between injury and operation should not influence the result

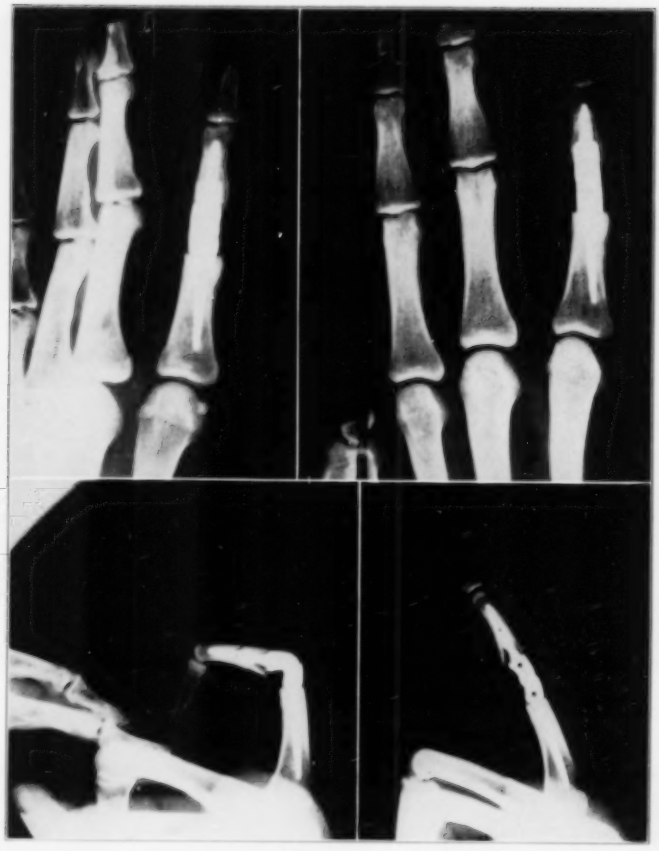

FIG. 4-B

Roentgenograms of index finger eight months after insertion of prosthesis. Note degree of active motion.

so long as the tendons and digital nerves are intact. An artificial joint will not restore function if the soft-tissue structures have been extensively damaged.

All our cases were the result of trauma, but the same type of replacement would apply to a diseased joint as long as the condition of the soft tissue permits. The procedure would be contra-indicated in the presence of any active inflammatory process—rheumatic or pyogenic in origin. In cases of hypertrophic arthritis the result should be favorable.

The procedure may be applied to the reconstruction of a damaged or diseased metacarpophalangeal joint, as illustrated in two of our patients (Cases 1 and 12). In all cases reported here, the prosthesis was used in place of either amputation or arthrodesis and was considered a form of salvage.

TECHNIQUE

The surgical technique to be described applies to the procedure involving the proximal interphalangeal joint; for replacement of other finger joints, the same principles apply.

Operation is performed with the patient under general anaesthesia and with an arm tourniquet. A straight, longitudinal, lateral incision is made over the joint[4]. The extensor mechanism is carefully defined, mobilized by incising the fascia longitudinally, and retracted to the opposite side. Any excess cicatrix is excised. The

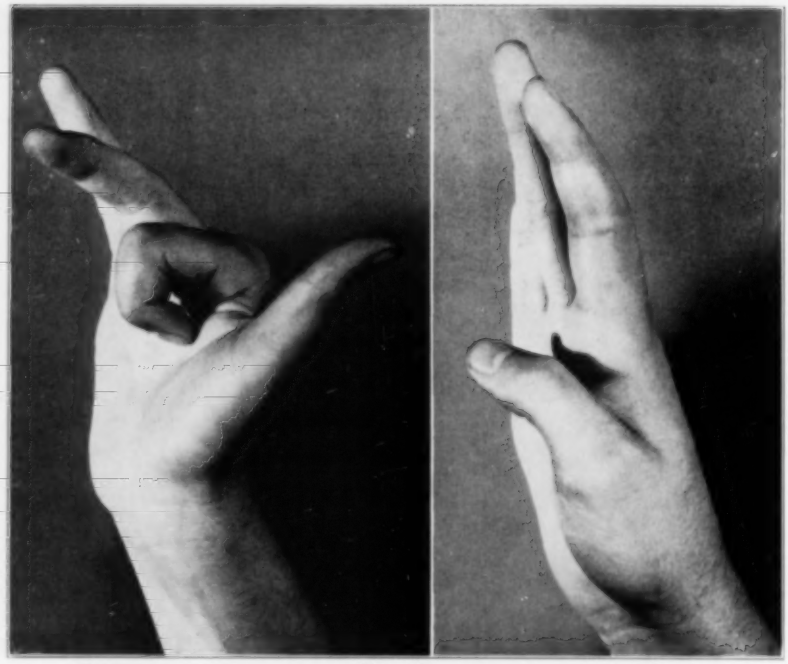

FIG. 4-C

Photographs of index finger showing degree of active motion eight months after operation.

FIG. 4-D

Roentgenograms of finger twenty-one months after surgery. Note range of motion and resorption in proximal phalanx.

joint is exposed by incision of the capsule laterally, and the collateral ligaments are excised.

The entire joint is resected with a bone cutter or a small Gigli saw, leaving a space of approximately one centimeter between the bone ends. The middle phalanx is then held with the phalangeal bone-holder while the medullary canal is prepared with a reamer. The medullary canal in the proximal portion of the bone is not round, but oblong in shape. This also applies to the distal portion of the proximal phalanx. In this area, the canal is prepared with the small chisel, so that the triangular shaped stem of the prosthesis may be fitted snugly.

Each half of the prosthesis is inserted separately. The distal half of the pros-

FIG. 4-E

Photograph of finger showing active flexion twenty-one months after operation.

thesis is tapped into place with the impactor until the intramedullary stem is well seated in the middle phalanx. The hub of the prosthesis should be flush with the bone stump. The proximal half of the device is inserted into the proximal phalanx in the same manner. A metal staple is then inserted through drill holes in the hinge portion and intramedullary stem of each half of the device. The site for the drill hole in the phalanx is determined by measuring with the staple itself. One prong of the staple is placed in the hole through the hub of the prosthesis and the bone is marked by placing the other prong on the mid-lateral surface of the phalanx. A hole is then drilled with a fine Kirschner wire until the drill penetrates the bone and enters the prepared hole in the medullary stem. After each staple is tapped into place, the prongs are bent, using sharp-nosed pliers, to lie flush with the bone surface, thus firmly anchoring the prosthesis to the phalanx.

When the two halves of the prosthesis are joined at the hinge-joint the finger should be straight, and there should be no abnormal rotation. Furthermore, there should not be appreciable shortening of the finger. The two parts of the hinge-joint are locked together with the small half-threaded rivet screw. The end of the screw is flattened and spread with a swaging tool which fits over the screw and turns down on the rivet end (Fig. 2). The device is tested for stability in extension and flexion and should glide easily from full extension to full flexion.

The wound is irrigated with saline solution and closed. The capsule is closed with fine catgut sutures and the extensor mechanism is replaced. The skin edges are approximated with everting sutures of fine silk, and the finger is immobilized in a position of extension until the wound is healed, usually ten to twelve days.

FIG. 5-A

Case 3. Roentgenogram showing ankylosis of proximal interphalangeal joint of the ring finger.

Elastic traction then may be applied to the involved finger until all reaction has subsided. Early active graduated exercises are performed until maximum function is attained. Occupational education is a helpful adjunct. No passive or forcible manipulation is permitted.

REPORT OF CASES

All patients in this series were in the younger military age group and all

FIG. 5-B

Figs. 5-B and 5-C: Roentgenograms thirty-nine months after prosthesis. Note degree of resorption of bone and sinking of device.

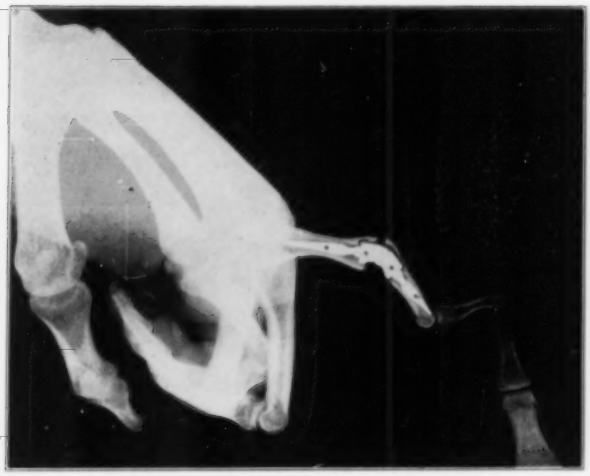

FIG. 5-C

FIG. 5-D

Photograph of finger showing boutonniere deformity thirty-nine months after operation.

FIG. 6

Case 6. Roentgenogram of finger twenty-eight months after operation. Note sinking-in effect. Patient had stiffness but no pain.

had irreparable joint defects of the finger secondary to trauma. They were referred to us for either arthrodesis or amputation. The time interval between injury and replacement arthroplasty varied from three months to two years. Of the fourteen patients on whom operation was performed, in two the metacarpophalangeal joint was replaced and in the rest, the proximal interphalangeal joint (Table I). Half of the patients had involvement of the second proximal interphalangeal joint. All had a residual fixed-extension deformity and there was roentgenographic evidence of joint disruption from an old fracture-dislocation. Three patients (Cases 2, 6, and 13) had concomitant injuries to the extensor tendon which required surgical repair, either at the time of prosthetic replacement or later.

RESULTS

The over-all results as revealed in Table I have been encouraging. Two of the fourteen case reports must be discounted because of insufficient follow-up period (Cases 5 and 14). The remaining twelve had follow-ups ranging from ten to thirty-nine months. Most of these patients retained a functional range of painless motion at the replaced joint. Case 1 and Case 9 (Figs. 4-A through 4-E) are representative. In addition, existing deformities were corrected obtaining a more normal appearing hand. The problem of lateral instability with the finger extended was not significant. In general, stability of the part was satisfactory except for two patients (Cases 7 and 8) who exhibited slight ulnar angulation due to migration of the stem of the prosthesis in the proximal phalanx. However, this did not interfere with function to any appreciable degree.

The problem of bone resorption and sinking of the prosthesis into the phalanges to a variable degree did arise in the earlier patients (Figs. 5-A through 5-D).

TABLE I

Case	Joint Replaced	Date of Operation	Follow-up (*Months*)	Range of Motion (*Degrees*)	X-ray Changes	Stability of Part	Symptoms	Occupation	Result (*Patient's rating*)	Result (*Examiner's rating*)
1	Left 4th metacarpo-phalangeal	12/21/53	38	160 to 110 (50)	Bone resorption, some sinking-in	Excellent	None	Clerk-typist	Satisfactory	Excellent
2	Right 4th proximal interphalangeal	3/10/54	13	165 to 95 (70)	Bone resorption, some sinking-in	Good	None	Carpenter-painter	Satisfactory	Satisfactory
3	Left 4th proximal interphalangeal	3/31/54	39	125 to 85 (40)	Bone resorption, some sinking-in	Good	No pain; boutonniere deformity	Draftsman	Satisfactory, 3 yrs.; now unsatisfactory	Failure
4	Right 4th proximal interphalangeal	7/7/54	31	180 to 130 (50)	Bone resorption, some sinking-in	Excellent	None	Typist	Satisfactory	Satisfactory
5	Left 2nd proximal interphalangeal	9/3/54	7	170 to 100 (70)	No x-ray	Not tested	None	Supply sergeant	Satisfactory	Insufficient follow-up
6	Left 2nd proximal interphalangeal	11/22/54	28	180 to 160 (20)	Sinking-in of device; bone block	Good	Stiffness; no pain	Farmer	Satisfactory, 2 yrs.; now unsatisfactory	Failure
7	Right 2nd proximal interphalangeal	5/4/55	17	175 to 125 (50)	Sinking-in 5 millimeters, stem through proximal phalanx	Excellent, ¾ of an inch shortening	None, plays golf	Administrator	Satisfactory	Satisfactory
8	Right 2nd proximal interphalangeal	5/25/55	12	175 to 120 (55)	Migration, proximal stem; loose screw?	Good; slight ulnar angulation	None	Aircraft mechanic	Satisfactory	Satisfactory
9	Right 2nd proximal interphalangeal	1/13/56	21	180 to 100 (80)	Resorption, proximal phalanx; loose screw	Good; ulnar angulation	None	Crypto-mechanic	Satisfactory	Satisfactory
10	Right 2nd proximal interphalangeal	3/7/56	19	175 to 85 (90)	Stem through middle phalanx	Excellent	None	Special investigation	Satisfactory	Satisfactory
11	Right 4th proximal interphalangeal	9/28/56	12	165 to 100 (65)	No resorption or sinking	Excellent (staples used)	Feels cold; prosthesis magnetized	Cryptograph repairman	Satisfactory	Excellent
12	Left 2nd metacarpo-phalangeal	9/28/56	10	170 to 135 (35)	No reaction	Excellent	Discomfort in cold weather	Driver and mechanic	Satisfactory	Satisfactory
13	Left 3rd proximal interphalangeal	1/17/57	10	160 to 90 (70)	None	Excellent (proximal staple)	Stiffness; no pain	Aircraft mechanic	Satisfactory	Excellent
14	Left 2nd proximal interphalangeal	6/19/57	5	175 to 90 (85)	No x-ray	Not tested	None	Farmer	Satisfactory	Insufficient follow-up

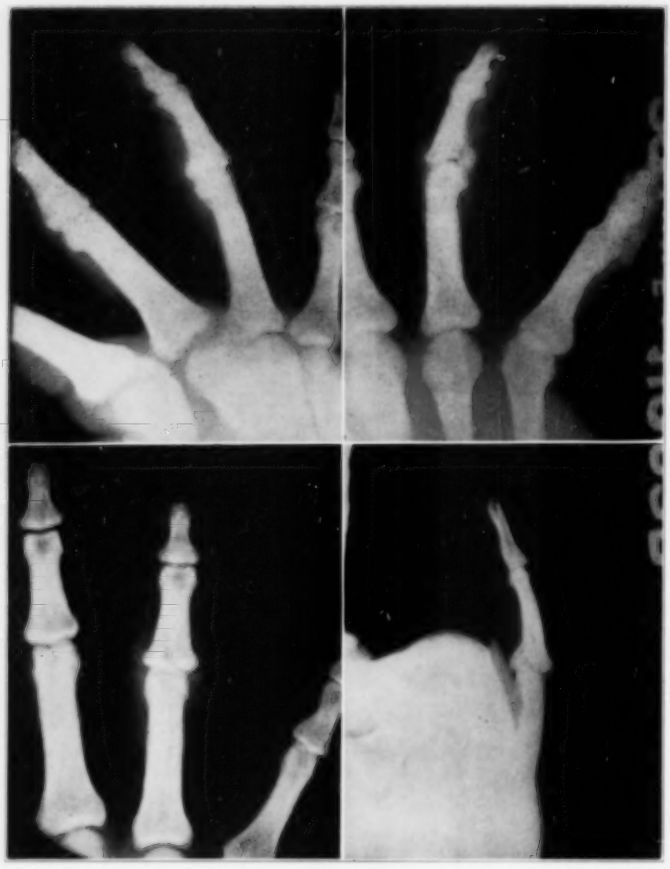

FIG. 7-A

Case 11. Roentgenogram of ring finger showing joint disruption and ankylosis from old injury.

Ordinarily, this difficulty became manifest ten to twelve months after surgery. Further observation revealed some shortening of the finger and loss of motion as a residuum of the sinking-in (Fig. 6). Subsequently (1956), a modification of the prosthesis, with the addition of a staple through both halves was devised in an effort to overcome this problem (Figs. 7-A through 7-D). To date the three patients (Cases 11, 13, and 14) in whom the modified prosthesis was used have exhibited no such difficulty.

In two patients (Cases 1 and 8) the screw in the hinged portion of the prosthesis eventually became loose and required tightening. This problem might be anticipated in such a device. However, the difficulty has been solved by the fabrication of a rivet type of half-threaded screw and a special swaging instrument. In two patients (Cases 7 and 10) the point of one of the medullary stems penetrated an adjacent joint (Figs. 8-A and 8-B). As yet, there have been no symptoms associated with this complication, and function of the fingers in these two patients was considered satisfactory.

The earlier prostheses were made of stainless steel and the present ones of titanium (Cases 11, 13, and 14). Titanium appears just as inert to tissue fluids and has the advantage of being somewhat lighter than stainless steel. To date no un-

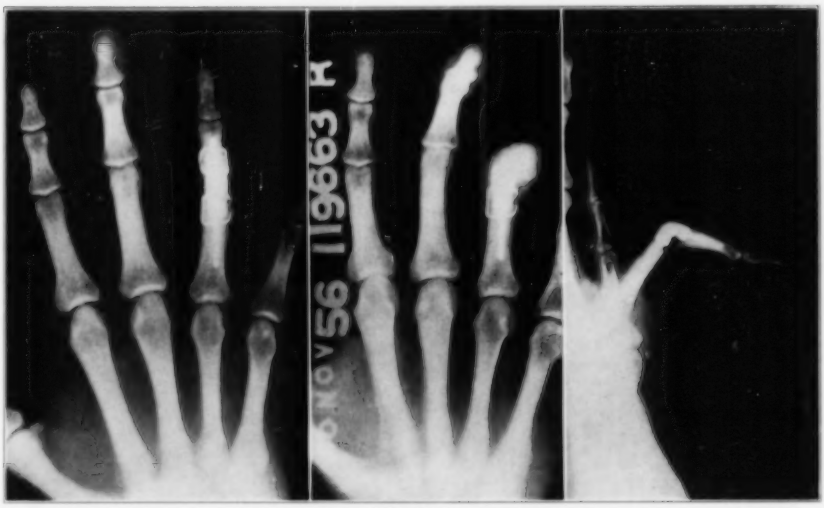

FIG. 7-B

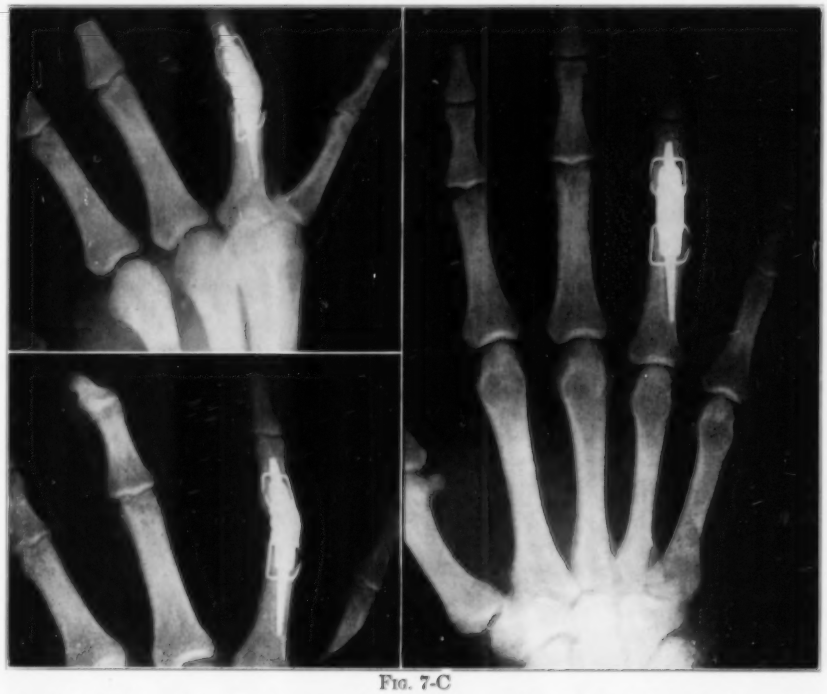

FIG. 7-C

Figs. 7-B and 7-C: Roentgenograms of hand showing prosthesis ten weeks and twelve months after surgery. Note the staples in the device and minimal effect of bone resorption.

toward tissue reaction to either metal material has been observed. The tendency of the early prostheses to migrate along the medullary canal after ten to twelve months is disturbing, even though at this date no pain or disability has resulted from this complication. It might be anticipated that sooner or later loosening of the prosthesis or penetration of its stem with an adjacent joint will cause diffi-

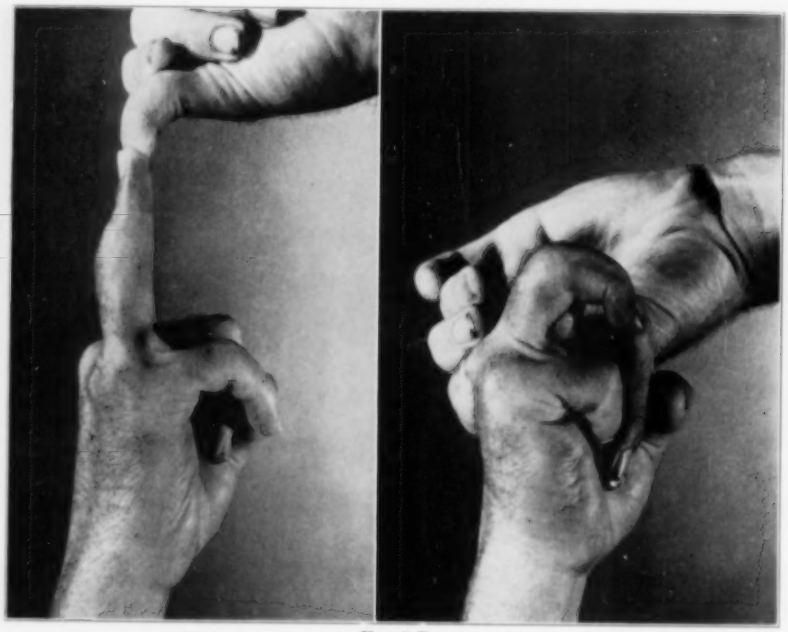

FIG. 7-D

Photographs of finger twelve months after operation showing degree of flexion.

FIG. 8-A

Case 10. Roentgenogram of index finger made nineteen months after operation. Note protrusion of distal medullary stem through the distal interphalangeal joint. Device was too long in this patient but he had no appreciable symptoms.

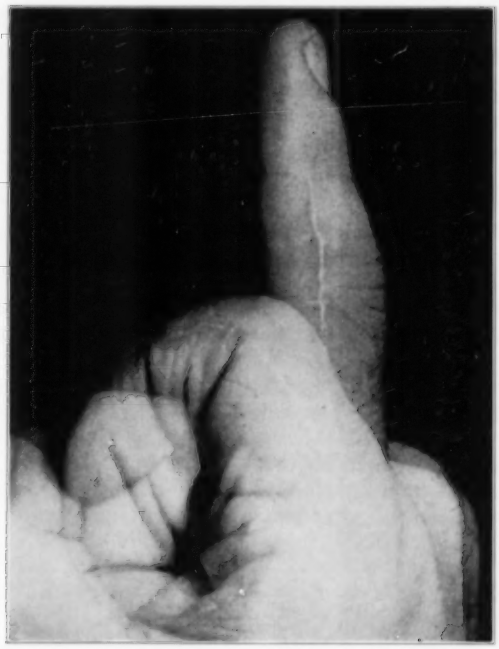

FIG. 8-B

Double-exposure photograph of index finger nineteen months after surgery showing range of motion.

culty. It is hoped that the use of staples will prevent this complication. As yet, none of the prostheses which were anchored with staples have shown any tendency to migrate. However, the patients in whom staples were used have only been followed twelve, ten, and five months respectively. In any event, we feel that the procedure has been justified since the patients have had several years of useful hand function. Furthermore, if the staples are found to prevent migration, the older prostheses can be replaced with the new which is anchored with the staples.

None of the patients had residual pain. Two patients (Cases 11 and 12) said that discomfort in cold weather necessitated their wearing heavy gloves. In one patient (Case 11) the prosthesis became magnetized in the course of his occupation. Other than the novelty of small metallic objects becoming attached to one finger at random, there were no significant symptoms. All the patients were primarily dependent on the use of their hands in their work. All except two expressed complete satisfaction with the results. The motivation of these patients was excellent and they readily accepted a prosthesis as an alternative to other surgical measures.

The examiners' rating was based on the degree of motion, the stability of the device, changes noted in roentgenograms, and residual symptoms in relation to the patient's occupation. An *excellent* rating was computed on the basis of active motion of over 50 degrees, clinical stability, roentgenographic evidence of intact prosthesis, absence of any untoward tissue reaction, no symptoms of significance, and performance of work without complaint. A *satisfactory* result was based on range of active motion of over 50 degrees, minimal or no symptoms, work performance without complaint despite mild clinical instability, and roentgenographic evidence of some degree of migration or loosening of the prosthesis. A rating of *failure* was given to a result not fulfilling the above criteria. In regard to the two failures (Cases 3 and 6), there is the alternative of arthrodesis, or more

likely reinsertion of the newer prosthesis. It should be noted that in both of these the results had been satisfactory from the patient's standpoint, for periods of three and two years respectively. Ten cases were given satisfactory to excellent ratings.

SUMMARY

A metal, hinged type of prosthesis has been developed for irreparably damaged joints of the finger in selected cases, as an alternative to amputation or arthrodesis.

This operation, a procedure of salvage, is performed in the hope of restoring some degree of useful function in an otherwise useless part.

Prerequisites for the procedure are: functionally restorable tendons, intact nerve supply, adequate circulation of the part, and good motivation.

Complications, consisting of sinking-in of the prosthesis and loosening of the screw, are discussed and solutions of these problems presented.

In ten patients of the twelve cases rated, a functional range of painless motion was restored and the cosmetic appearance of the hand improved.

All patients returned to full military duty and were engaged in specific occupations requiring use of the hands.

The results in this brief series have been sufficiently encouraging to warrant further attempts at this method of replacement arthroplasty.

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(Continued from page 70)

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Periarticular Soft-Tissue Changes as a Late Consequence of Burns

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Burns, depending on the extent of tissue damage and such complications as shock and infection, may lead to serious local and systemic changes in the body. There may be reduction of vitality and direct damage to the burned tissue as well as disturbances in the composition of plasma and intercellular fluids and in the permeability of the cell membranes.

Burns and their complications result in a series of cosmetic and functional sequelae after healing. At the Clinic of Plastic Surgery, Charles University, Prague, we examined, both clinically and roentgenographically, 750 patients who had burns and scalds of different extent and degree. We concentrated particularly on the reaction of bone and joints to burns. Changes around the joints did appear in twenty-five patients (3.3 per cent of the group); roentgenographic and histological examinations revealed calcification and ossification of periarticular soft tissue. The joints affected were the major ones, particularly the elbow, knee, and ankle. Periarticular change in the hip and shoulder was rare and we never saw any soft-tissue change in the small joints of the hand or foot even when the skin over these was seriously damaged. We felt we could exclude other possible origins of calcification in patients with periarticular change since there was no history of injury except the burning itself. Roentgenograms were made at admission and repeatedly afterwards so that we could follow, step by step, the beginning of calcification in the soft parts and how it increased in size and eventually attained a definite structure.

The roentgenographic appearance of calcification and ossification after burns is quite varied but we can, however, recognize the following fundamental types of changes:

1. Small insular or linear calcification and ossification in soft parts near the bone but not connected to the bone. This was found most frequently on the medial aspect of the knee by the femoral condyle, in the same area where post-traumatic Pellegrini-Stieda ossification appears. In some of these patients the original shadow of calcification changed to ossification as indicated by the trabecular pattern, the cortical layer, and clear and sharp delineation.

2. Periosteal thickening varying in depth and in length, similar to other periostitis but sometimes combined with calcification and ossification of muscle attachments.

3. Limited exostosis.

4. Extensive calcification and ossification of the soft tissue around the joint involving the capsule and its adjacent structures and sometimes leading to a bony bridging of the joint and extra-articular ankylosis. These bizarre aberrations are usually found at the elbow joint. The joint space, however, is well preserved and the articular cartilage is not affected.

CASE REPORTS

CASE 1. A severe electrical burn was received by J. F., a man, thirty-one years old, in May 1954. Forty-three per cent of the skin was affected, mostly with second and third-degree burns involving the lower part of the abdomen and the limbs. The burns about the knee and ankle were third degree. The patient was in severe shock initially and was under treatment for many months. Analysis of the blood showed that the serum calcium and phosphorus

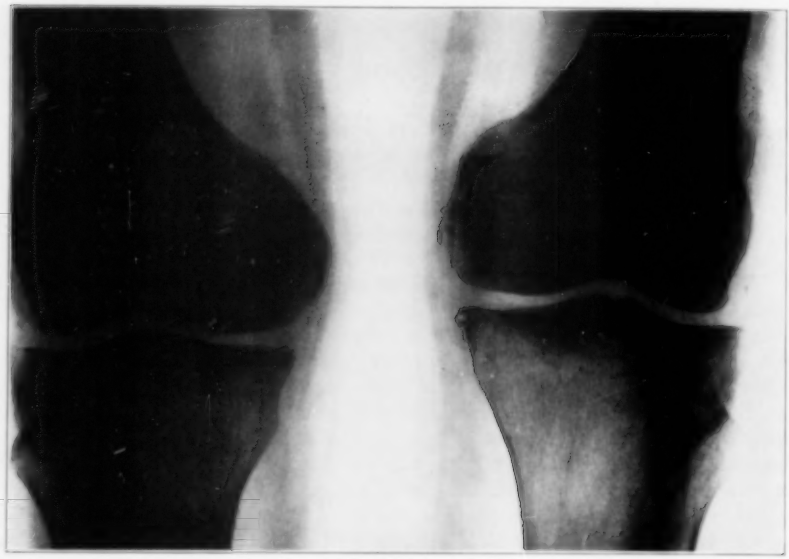

FIG. 1-A

Case 1. Roentgenograms made in June 1954 of both knees showing the development of cloudlike calcification on the inner surfaces of both medial femoral condyles.

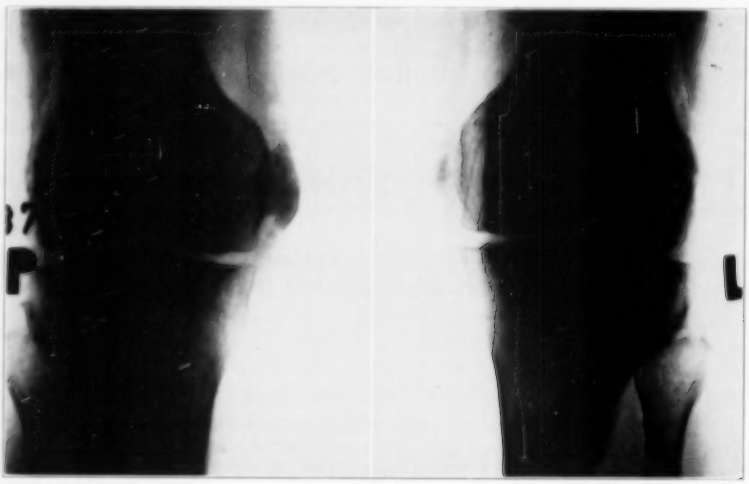

FIG. 1-B

Roentgenogram made in July 1956. Progression of the process has stopped. On the right, joining the femoral condyle, is a spongelike exostosis. On the left side calcification has changed into ossification which, however, remains separated from the bone.

were within normal limits, but that the serum alkaline phosphatase rose as high as 13.2 Bodanski units. The burned surfaces became infected by *Staphylococcus pyogenes aureus hemolyticus, Bacillus pyocyaneus,* and particularly by *Streptococcus beta hemolyticus.* During treatment calcification developed gradually on the soft parts about the knee and ankle joints. In the summer of 1954 calcification appeared on the inner surfaces of both medial femoral condyles. At first there were homogenous cloudy shadows (Fig. 1-A) which gradually became ossified. On the left the process did not develop significantly but on the right side it continued to enlarge ultimately joining the femoral condyle to form a spongelike exostosis with the architecture of lamellar bone (Fig. 1-B). These bone formations were easily palpable. Ossification also developed at the ankle joints, but this seemed more like periostitis, particularly on

FIG. 1-C

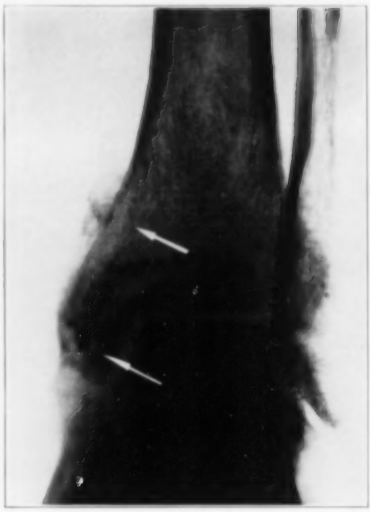

FIG. 1-D

Fig. 1-C: Periosteal apposition on the medial aspect of the right ankle joint.
Fig. 1-D: Roentgenogram showing similar changes in the left ankle joint.

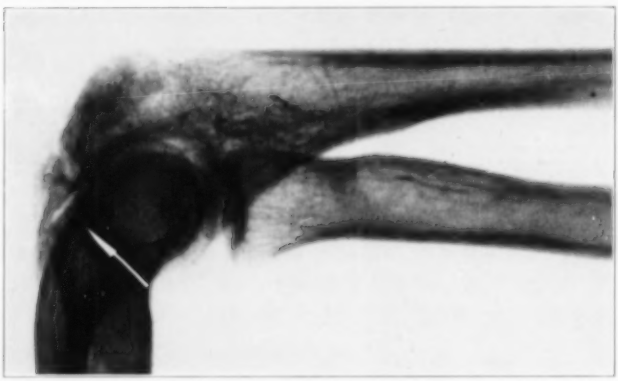

FIG. 2

Case 2. Ossification of the insertion of the triceps of the left elbow.

the medial aspects (Figs. 1-C and 1-D). The progression ceased at the end of two years. The range of motion of the affected joints remained somewhat limited. Poor blood circulation presented an additional difficulty.

CASE 2. A nineteen-year-old nurse was burned in November 1956 when an oxygen tank exploded. She had second and third-degree burns chiefly on the upper portion of the limbs and face. The burns involved 44 per cent of her body surface. After initial treatment for severe shock, she had a series of skin transplantations. There was considerable suppuration in her burns due to infection by *Staphylococcus pyogenes aureus hemolyticus, Streptococcus beta hemolyticus* and *Bacillus pyocyaneus*. In the course of three months, calcification developed in the left elbow in the region of the triceps insertion with associated loss of elbow motion. Both flexion and extension were limited by about thirty degrees (Fig. 2).

CASE 3. M.S., a woman fifty-one years old, was burned in July 1955 as the result of the explosion of a gasoline stove. She had second and third-degree burns involving 60 per cent of her body surface with third-degree burns of the left elbow. Healing was complicated by infection with *Streptococcus beta hemolyticus* and *Staphylococcus pyogenes aureus hemolyticus*. The patient resisted all efforts to exercise and mobilize the left elbow complaining of great pain.

FIG. 3

Case 3. Lateral view of the left elbow showing ossification of the posterior aspect of the joint.

The joint stiffened in 110 degrees flexion owing to the development of massive ossification on the posterior surface of the joint (Fig. 3). While calcification and ossification were developing, attempts were made to prevent stiffness by passive movement of the joint under narcosis and by the injection of hyaluronidase into the vicinity of the joint. Unfortunately, these steps did not meet with the desired result.

CASE 4. L.C., a woman thirty-three years old, had second and third-degree burns involving 37 per cent of her body surface. Her burns were limited primarily to the face and upper extremities with third-degree burns about the elbows. Massive infections of the burned surfaces developed due to *Staphylococcus pyogenes aureus hemolyticus, Proteus vulgaris,* and *Pseudomonas aeroginosa.* Healing of the burns was delayed and the patient would not exercise her joints sufficiently. After seven months in the hospital flexion deformities developed in both elbows with only 10 to 20 degrees of active motion. At this time ossification had begun to develop in both elbows (Figs. 4-A and 4-B). Attempts to arrest this process, including injections of hyaluronidase, failed. On the right side, there was a shell-like mass of ossification in the joint

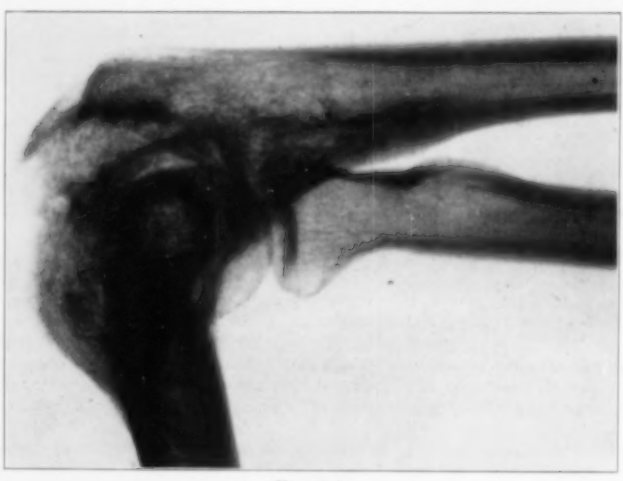

FIG. 4-A

Case 4. Roentgenogram of the elbow showing ossification of muscle insert of the posterior aspect on the continuation of the olecranon.

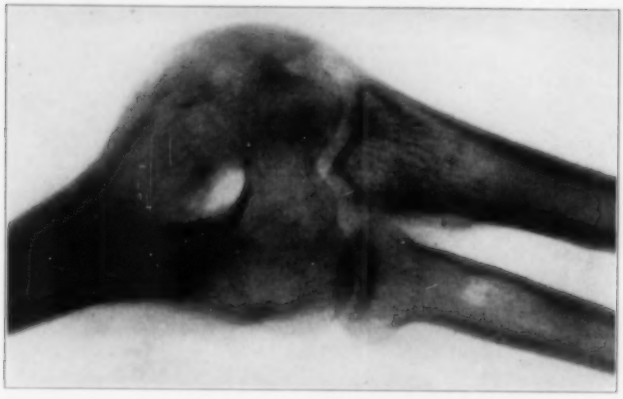

FIG. 4-B

Ossification in the joint capsule on the medial surface of the elbow.

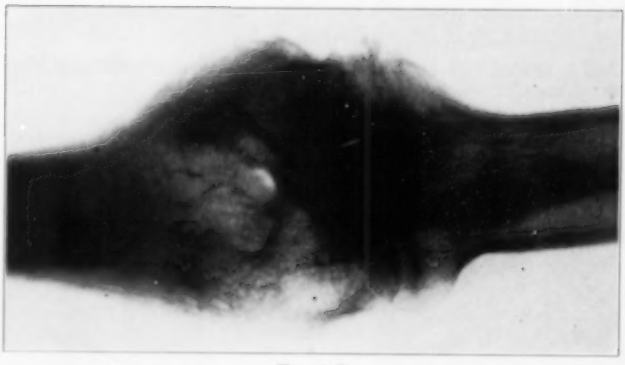

FIG. 4-C

Roentgenogram made ten months after operation showing some regeneration of the bone mass which had been partially removed.

capsule (Fig. 4-B). In an attempt to restore motion in this joint the ossified tissue was excised by an operative procedure. This increased active motion to 70 degrees and passive movement to 90 degrees. However, during the ensuing year ossification gradually began to recur and active movement decrease (Fig. 4-C).

CASE 5. M.M., a woman forty-four years old, received second and third-degree burns involving 17 per cent of her body surface. The right upper extremity was involved primarily with third-degree burns of the elbow and second-degree burns of the shoulder. Healing was slow being complicated by infection. During this time the serum calcium ranged from 9.2 to 10.9 milligrams per 100 milliliters, while serum phosphorus ranged between 2.5 and 4.0 milligrams per 100 milliliters. Her alkaline phosphatase rose as high as 18.2 Bodanski units. The patient refused to move her right elbow because of pain. At first a cloudlike calcification (Fig. 5-A) occurred about the elbow joint which subsequently changed to mature ossification (Fig. 5-B). A similar ossification developed in the periarticular tissues about the shoulder on the same side (Fig. 5-C). In the course of eight months the process gradually ceased and no further growth of ossification occurred. The elbow became stiff at 100 degrees of flexion and abduction of the shoulder was limited to 50 degrees. Portions of the ossified mass about the elbow were removed surgically but function was not appreciably improved.

Histological examination of the removed tissue showed it to be fibrous, vascular, highly cellular connective tissue with metaplastic bone formation. Bone trabeculae, Haversian canals, and numerous osteoblasts were visible, but no cartilage or muscle was found (Fig. 5-D).

In the remaining twenty patients there were similar findings, generally somewhat milder, which corresponded roentgenographically to those mentioned.

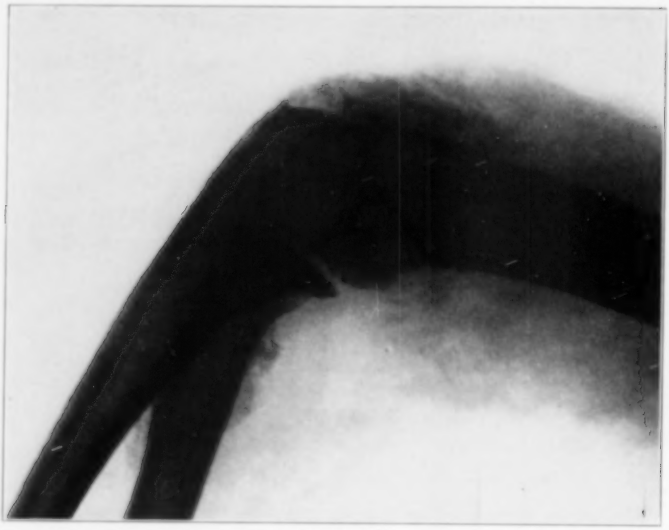

FIG. 5-A

Case 5. Lateral view of the right elbow made three months after injury, showing granular calcification and periosteal apposition.

FIG. 5-B

FIG. 5-C

Fig. 5-B: Roentgenogram made eight months after injury showing stabilized calcification and extra-articular ankylosis of the joint.

Fig. 5-C: Ossification has developed in the periarticular tissue of the right shoulder.

DISCUSSION

Calcification and ossification of the soft tissues is frequently seen on roentgenographic examination and often as incidental findings. These may be divided into two main categories as described by Zuppinger:

1. The so-called metabolic calcification in generalized illness which is accompanied by an elevation of the calcium and phosphorus levels in the serum.

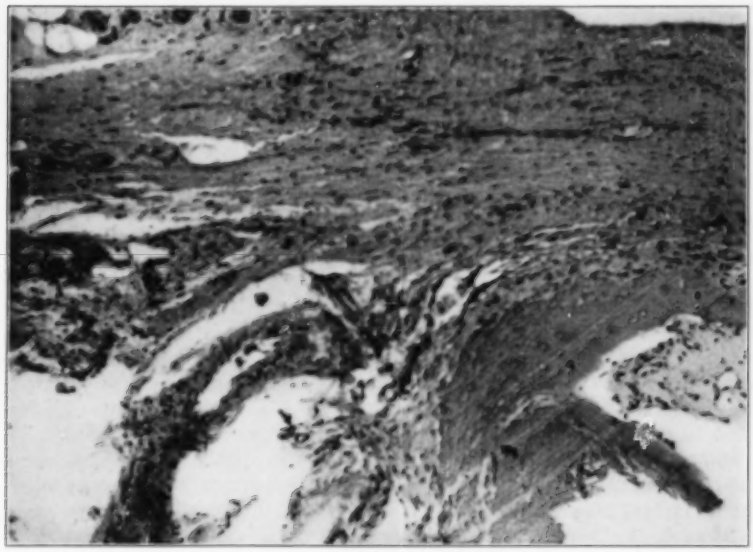

FIG. 5-D

Photomicrograph (hematoxylin and eosin, ×90) of osseous tissue removed from the elbow.

The excess salts are not adequately eliminated from the body, and are deposited in different organs such as kidneys, lungs, and connective tissue.

2. The degenerative calcification which is chiefly due to a local condition which develops when the tissue has been damaged by accident, degeneration, inflammation, necrosis, or a trophic disturbance. The calcium and phosphorus serum levels in this condition are as a rule normal.

In both types of calcification there appears to be some primary damage to the tissues in which calcification occurs. The simple rising of the level of calcium and phosphorus in the blood plasma does not lead to such change in normal non-calcifying tissue according to Hass.

Generally, the reasons for calcification and ossification are various injuries to the joints, such as ligament damage, dislocation and fractures, or injuries of the spinal cord, particularly those which lead to paraplegia and trophic changes. Dörffel described calcification in subcutaneous scars as being formed over the course of many years after the injury. Findings resembling ours were described by Johnson as atypical myositis ossificans or heterotopic ossification. We feel that the name, myositis ossificans, is incorrect as our histological studies and roentgenograms showed the changes to have occurred entirely around the capsule of the joint and at the insertion of ligaments and muscles. We feel the name, periarticular calcification and ossification, or osteoma periarticulare, would be more correct.

In evaluating our series of patients we found in most instances the condition had several common characteristics. They all had wide superficial burns of considerable severity which always involved the skin above the joint in which calcification and ossification had developed. The burn was never so deep as to burn bone or joint and suppuration of the joint did not develop as the intact articular surface and joint spaces prove. In some patients we noticed an increase in the level of serum alkaline phosphatase which indicated activation of bone minerals. The level of calcium and phosphorus in the serum was not markedly altered; this finding agrees with the experiences of other authors.

A conspicuous aspect in all patients was the bacterial infection of the burned surface. Besides the more common infection of *Staphylococcus pyogenes aureus hemolyticus,* we frequently noted *Streptococcus beta hemolyticus* which is dreaded because it leads to obstinate suppuration, retards healing, and, hence, delays early active exercise.

There was no obvious age predilection; the youngest patient was two years old and some were elderly.

Calcification and ossification sometimes developed as early as five to six weeks after the burning. Generally it attained a definite form in three to six months or, at the latest, by the end of the second year.

That this calcification and ossification has a direct etiological connection with the burning itself, we cannot doubt. However, the burn alone cannot cause the condition; local changes in the tissues in the vicinity of the joint seem to be necessary. We believe this to be pertinent; in the majority of those burned such changes did not take place at all, even in patients with burns about multiple joints. Only particular ones became involved. We observed that calcification seemed to develop particularly in joints whose function was impeded.

In spite of intensive studies in recent years the pathological causes of soft-tissue calcification are not yet fully explained. Undoubtedly a series of local and systemic factors must be taken into consideration. The most important probably are the changes of the vitality, chemistry, and pH of the tissues that calcify, the total chemistry of the blood and intercellular fluid, the circulatory disturbances, and damage to innervation. All these factors may be components in the final process of ossification and calcification. However, there is no doubt that in the case of severe burns, conditions often occur which predispose to soft-tissue calcification around the joints.

TREATMENT

Once calcification and ossification has already taken place the treatment is quite limited. It seems impossible to stop this condition when it has advanced despite passive exercise and injections of hyaluronidase into the area. As in the case of similar post-traumatic changes, surgical removal of the ossification is often unsatisfactory since re-ossification frequently occurs.

It is, therefore, indubitably more important to prevent the condition than to treat the problem of calcification and ossification once it has developed. Measures must be taken as soon as possible after the burning to protect the wounds from infection as massive suppuration prolongs the healing and furthers general debilitation. For the same reasons it is necessary to gain skin coverage by graft as rapidly as possible. As soon as the condition of the patient permits, active and passive exercises of the limb should be initiated. It is, however, necessary to avoid forced motion which may lead to trauma of the joints and soft tissues and encourage the development of calcification. It is only with careful and purposeful treatment that we can prevent the serious secondary changes about the joints which make the patient, despite good skin healing, a permanent invalid.

SUMMARY

Periarticular calcification and ossification occurred in twenty-four (3.3 per cent) of 750 patients with burns. Various types of tissue change were observed, both clinically and roentgenographically. These late periarticular changes were so closely associated with extensive and severe burning that the possibility of other traumatic sources was eliminated. On the basis of their observations and experience the authors believe that infection of the wounds and insufficient and unsuitable rehabilitation during treatment might well be a cause of calcification and ossification.

Attempts to cure mature or developing ossification met with little success both cosmetically and functionally. On the other hand, prevention of infection

and strict asepsis in the treatment of burned surfaces are important as is rapid skin coverage. These methods will shorten the time of treatment and will allow early careful exercise of the joints so that stiffness may be avoided.

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Correction of Chronic Dorsal Subluxation of the Proximal Interphalangeal Joint By Means of a Criss-Cross Volar Graft*

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Chronic posterior subluxation of the middle phalanx upon the proximal phalanx may occur as a result of forceful hyperextension of the proximal interphalangeal joint with an avulsion of the volar ligament, particularly if immobilization of the finger is carried out inadequately after injury. Minor degrees of subluxation undoubtedly are common and asymptomatic. Unless the joint locks partially or completely in some position of hyperextension, the patient is unlikely to call the condition to a physician's attention. The condition of locking in hyperextension sometimes is seen in severe athetosis and may follow sectioning of the flexor digitorum sublimis tendon.

The patient's complaints are of complete or incomplete locking that may require passive assistance to initiate flexion. Pain may be mild. Symptoms commonly extend over many years. The pathological findings in cases of proximal interphalangeal hyperextension due to trauma have been described by Kaplan and Portis.

Correction of this condition, once it has occurred, requires either repair of the torn volar ligament or reconstruction of a ligamentous substitute. A review of the literature reveals only three reports of surgical repair in this condition. Capurro and Russi [4] described one case in which a strip of fascia lata was looped

* Read at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., February 1, 1958.

FIG. 1-A

FIG. 1-B

Fig. 1-A: W. C. H. Preoperative photograph showing extension of the proximal interphalangeal and flexion of the distal interphalangeal joint of the ring finger.
Fig. 1-B: Preoperative photograph showing hyperextension of the little finger.

FIG. 1-C

Preoperative roentgenograms illustrating hyperextension of the proximal interphalangeal joint of the little finger and severe traumatic arthritic changes in the fourth metacarpophalangeal joint.

over the proximal end of the middle phalanx between the extensor tendon and the bone; the ends were passed volarward and crossed beneath the flexor sheath, and the free ends were then passed subcutaneously and sutured into the common extensor tendon proximal to the metacarpophalangeal joint. The photographs accompanying this case portrayed an excellent functional result. Bate, in 1945, reported one case of post-traumatic subluxation which was treated by reattachment of the volar ligament and suturing of the lateral ligaments in a shortened and flexed position. No further instability occurred. The patient was stated to have full flexion and extension to 160 degrees, with good function. In 1954, Portis described two cases in which repair of the volar plate was carried out. In one case, subperiosteal advancement of the ligament from the proximal phalanx was necessary. Motion in one case was described as between 165 degrees to 140

FIG. 1-D

FIG. 1-E

Photographs made after operation show range of extension and flexion of ring and little fingers.

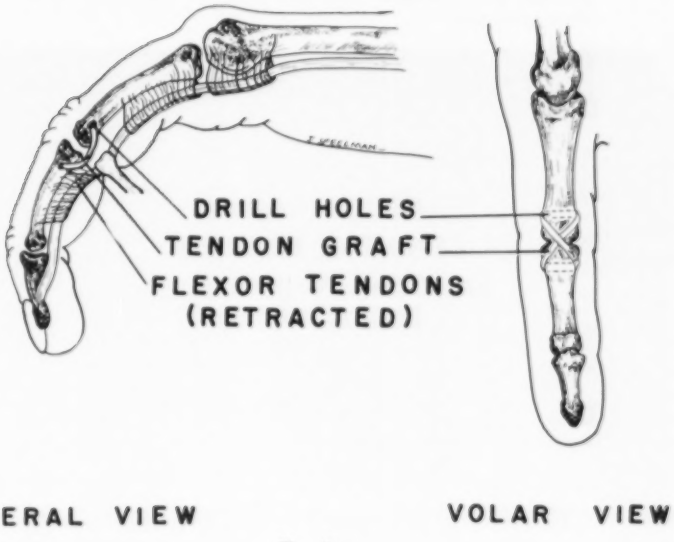

FIG. 2

Drawing shows the operative technique employed for correction of chronic or recurrent subluxation of the proximal interphalangeal joint.

degrees; the other from 175 degrees to full flexion. Furlong suggests opening the volar plate transversely to produce scarring and thereby limit extension.

A technique of reconstruction of the volar ligament was described by Bunnell; the technique is similar to that used by the author.

In this report, three chronic subluxations of the proximal interphalangeal joint seen in two patients will be presented and a technique for volar-plate substitution will be described.

W. C. H., a school teacher, forty-five years old, gave a history of chronic subluxation of the proximal interphalangeal joints of the right ring finger and little fingers following a severe injury twenty-seven years previously. The patient's hand was first examined in October 1954. At that time most of the symptoms were referred to the ring finger which, he stated, had begun to catch and lock a few months previously. He also noticed swelling of the joint and experienced pain. In order to flex the finger, passive assistance by an adjacent finger was required. He also noted that the proximal interphalangeal joint of the little finger was hyperextending but not locking. Examination of the hand revealed hyperextension of all proximal interphalangeal joints—the index finger extending to 200 degrees, the long,

FIG. 3-A

H. H. Preoperative photograph showing hyperextension of the proximal interphalangeal joint and flexion of the distal interphalangeal joint.

FIG. 3-B

Roentgenograms made before operation show the deformity.

ring, and little fingers to 220 degrees (Fig. 1-A). Crepitus was present in the proximal interphalangeal joint of the ring finger, and ulnar deviation of the middle phalanx was noted. Surgical repair of the ring finger was carried out on February 23, 1955.

The following surgical technique was utilized (Fig. 2). The joint was approached through bilateral dorsolateral incisions three centimeters in length. The lateral bands were retracted dorsally and the flexor sheath was separated from the joint. Examination of the joint revealed the lateral ligaments to be intact. The articular cartilage revealed severe traumatic arthritis. No volar ligament was recognizable. Transverse holes were drilled about four millimeters proximal and distal to the joint surfaces and at a right angle to the long axes of the bones. Through these holes was threaded a section of tendon, two millimeters wide and ten centimeters long, that had been previously removed from the palmaris longus tendon. The tendon was passed through one hole, the ends were then crossed over the volar surface of the joint and the longer end was passed through the

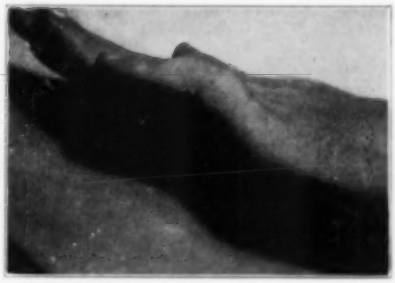

FIG. 3-C

FIG. 3-D

Photographs made after operation show the range of extension and flexion.

other hole and sutured to the shorter, with the joint held in about 30 degrees of flexion. After placement, the tendon was in the shape of a figure-of-eight. The finger was splinted in flexion for three weeks.

On March 6, 1956, a similar repair of the little finger was carried out, as well as a rotation osteotomy of the proximal phalanx of the ring finger to overcome the ulnar deviation (Figs. 1-B and 1-C). When last examined on November 1, 1957, the patient had full flexion of both fingers, the little extending to 180 degrees, the ring finger to 175 degrees (Figs. 1-D and 1-E).

H. H., a male statistician, thirty-six years old, was seen on January 20, 1956, because of an irreducible dislocation of the proximal interphalangeal joint of the left little finger without any particular trauma (Figs. 3-A and 3-B). The patient stated that the involved joint was dislocated twenty years previously while he was playing basketball. The details of the initial treatment were not recalled. Since that occasion, the finger frequently would dislocate but reduction always was easily accomplished. The present dislocation had occurred approximately one month prior to the patient's visit. The examination of the finger revealed hyperextension of the proximal interphalangeal joint with flexion of the distal joint. Surgical repair of the joint was carried out on January 25, 1956, by means of the technique previously described. When last examined on October 30, 1957, the joint extended to 155 degrees and there was slight limitation of flexion. There was a tendency toward hyperextension of the distal joint (Figs. 3-C and 3-D). Function was described by the patient as being much improved as contrasted to the twenty-year period of repeated episodes of chronic subluxation.

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Surgery of Tophaceous Gout

A Case Report *

BY HAROLD W. WOUGHTER, M.D., FLINT, MICHIGAN

Gout is an old and mysterious disease. Its exact cause remains obscure. Except for a few conscientious medical observers its very familiarity has caused investigative neglect. Talbott, Bartels, and Neuwirth have outlined the medical management soundly, and rationalized the therapeutic value and diagnostic aid of the new agents as they appear.

The rarity of surgical intervention in the treatment of gout is evident by the fact that in the last twenty-six years only a few articles dealing with surgical treatment of tophaceous gout have appeared. Linton and Talbott reported eleven patients operated upon for removal of tophi; relief of pain was obtained in all. They remarked that in one hundred years from 1835 to 1935 only seven cases of gout were operated upon for the treatment of tophaceous deposits at the Massachusetts General Hospital, three for evacuation of tophi, and four for amputation. It is for fear of the ignorance of the benefits of surgery in some cases of gout that we report the surgical management of this interesting case. A report of one case shows a wholesome disrespect for conventional medical investigation, but this case report does invite critical interest. The purpose of this presentation is to show the advantages of surgery in the treatment of tophaceous gout. The peculiarities of the disease lend themselves effectively to selective surgical attack on the tophi.

At first glance, hands crippled by one of the collagen diseases may clinically resemble gouty arthritis with tophi. Pathologically, the method of distortion differ. In gout, normal structures are encroached upon by deposits of urates, in contrast to the infiltration of connective tissues in the collagen diseases. The neurovascular systems are pushed aside by the developing tophi, encircled or trapped, but not invaded.

FIG. 1

Both feet in 1951.

*Read at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., February 1, 1958.

FIG. 2

Both hands in 1951.

The urge to remove tophi completely is tempting, but the tophus is often the sole remaining architectural framework for support and function. Sufficient excess can be removed to permit the wearing of shoes, gloves, or clothing and to give relief from pain, with no apparent risk of return of the deforming obstructions. This may be explained by the fact that urate-crystal deposits are

FIG. 3

Left foot, 1956.

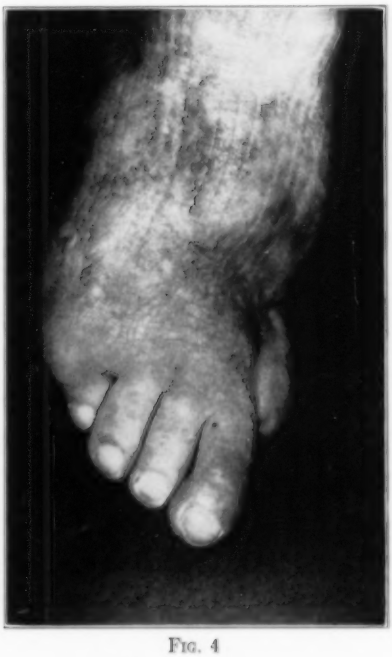

FIG. 4

Right foot, 1956.

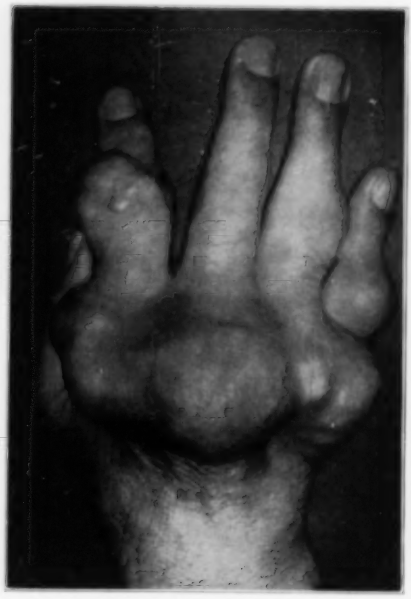

FIG. 5
Right hand, 1956.

FIG. 6
Right hand, 1956.

in the spaces between the connective-tissue fibers. The scar is hyalinized connective tissue with no spaces between fibers for the deposit of urates.

Gout has a predilection for the smaller bones and joints of the hands and feet. In larger joints it runs a much milder course; the osseous changes are less, or absent; and, although tophi may continue to enlarge, they seldom restrict function sufficiently to warrant surgical intervention.

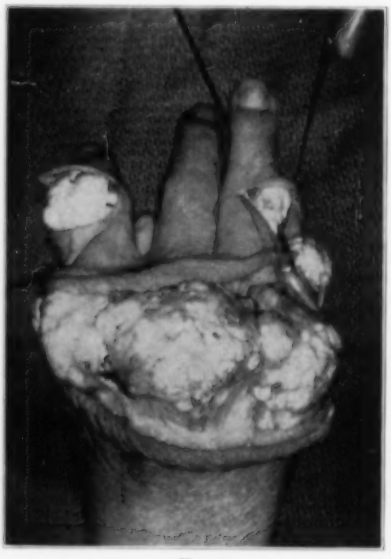

FIG. 7
Right hand at operation.

FIG. 8
After excision of tophi.

FIG. 9

FIG. 10

Right hand after operation.

E. M., a retired male factory worker, sixty-five years old, had symptoms of gout for the first time twenty years ago. In 1951 he sought surgical aid because of his inability to wear shoes, and a large draining tophi (Fig. 1). Tophi were removed from the heel and lateral side of the left foot. The draining tophus, involving the metatarsal to the great toe on the right, was removed by amputation of the first ray near its base. Tophi were noted at the knees, elbows, wrists, and hands (Fig. 2); these were not disturbed.

In October 1956, he again sought surgical relief because of difficulty in using his hands. The tophi had increased in size, seriously interfering in the functional use of the hands

FIG. 11

Left hand, 1956.

FIG. 12

Left hand, 1956.

FIG. 13

Left hand at operation.

FIG. 14

Left hand after operation.

for minimal daily requirements. At this time it was noted that all of the original tophi left undisturbed in 1951 had progressed. This was not true at the sites of operation, especially on the left foot where the urate deposit had been shaved to conform with the contour of the foot and the skin had been closed (Figs. 3 and 4).

The right hand was operated upon first because it was the least seriously involved. We wished particularly to observe the destruction by the tophi and the progress of wound-healing and functional return (Figs. 5 and 6).

At operation, the tendons were seen to be pushed aside or to be trapped in the tophi.

FIG. 15

Bone graft has united.

FIG. 16

Left hand, result.

Fig. 17

Left hand, result.

The urates were deposited between the tendon fibers (Fig. 7). The extensor tendons to each finger were spared. Complete removal of all urates was not attempted (Fig. 8). An acute attack of gout in the right shoulder occurred on the first postoperative day; this responded in five days to maximum doses of colchicine. The wounds healed promptly without drainage (Figs. 9 and 10), and the patient requested operation on the other hand during the same hospital stay.

The left hand presented a reconstructive challenge (Fig. 11). The index and long fingers were being bypassed. It was extremely difficult for the thumb to reach the right finger because of gouty joint changes. The middle and distal phalanges of the index finger appeared to be normal.

Roentgenograms revealed the osseous defect of medullary tophi, both polytopic and polyarticular, with subluxation of joints, ensuing inhibition of movement, and pronounced osteolytic manifestations. When the delicate periosteal shield formed around the confluent tophus, the bone appeared as though distended, then lost as if the attempt to limit the tophus had been overcome (Fig. 12).

The index finger tophus was removed, saving the vascular bundle with the middle phalanx (Fig. 13). The tourniquet was released and the blood supply to the phalanx was seen. It was decided that this phalanx could be moved to the long finger to replace that involved by the tophus.

In removing the lesion from the long finger, a cup-shaped bony shell was left to receive the cartilaginous end of the index phalanx, which was transferred with its blood supply. The proximal cartilage was removed and fixed with Kirschner wires (Fig. 14). The wounds healed, and the wires were removed in three weeks. Union progressed without incident (Fig. 15).

Figures 16 and 17 show the results after operation and healing. The patient received preoperative treatment with colchicine and no acute attack of gout resulted from this procedure.

SUMMARY

We believe this case emphasizes some peculiarities of gout:

1. Unaffected parts of a crippled digit can be transferred with the blood supply and effectively utilized in reconstructive procedures.

2. Osteogenesis will take place if bone has not been directly involved with a urate deposit.

3. Incomplete removal of tophi is not necessarily followed by return of the deforming overgrowth.

4. Wounds heal well even with extensive dissection and incomplete removal of the gouty lesions.

5. Early surgical intervention of progressive tophi of the hands is recommended.

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DISCUSSION

Dr. Robert E. Carroll, New York, N. Y.: Gout is an ancient disease and was originally called *podagra*. The name was derived from the Greek, meaning a painfully attacked foot. So frequently has the foot been the site of involvement in gout that it has become almost synonymous with the disease itself. We tend to forget that it does involve the hands as well. In the hand, however, the occurrence is relatively low. The diagnosis should be relatively easy to make by blood studies and roentgenograms. A more frequent disability in the hand is the clinical picture presented by an acute calcium deposit. This should not be misleading and has, of course, no relationship to gout. An excellent reference on this subject is a monograph called *Gout*, written by Dr. John H. Talbott *.

The deposition of urates in the hand usually is a slow process and the neurovascular bundle is not damaged—as Dr. Woughter has pointed out in his paper. This fact allows rather extensive surgery with a reasonably good prognosis. Surgical scars do heal nicely and apparently prevent return of urate deposits in that area. It is felt that there are two major indications for surgical intervention. The first indication is to prevent mechanical disability. When the deposits cause joint instability and digital angulation, they should be removed at an early date. If a deposit on a finger grows in size so that it is difficult to put on a glove, it should be removed. The second major indication for surgical care is involvement of the skin covering the tophus. We should not wait until the skin becomes necrotic and a draining sinus is found. This is an invitation to infection.

Dr. Woughter is to be congratulated on rehabilitating, surgically, two hands. The method of transferring the phalanx from the index to the middle finger along with its vascular pedicle is certainly ingenious. Two questions come to mind regarding this procedure: Would a bone-bank graft of cancellous material have fused just as well? Could the phalanx have been used as a free graft without the vascular pedicle and just as firm an arthrodesis obtained?

* Talbott, John H.: Gout. New York, Grune and Stratton, 1957.

An Analysis of Muscle Action and Joint Excursion During Exercise on a Stationary Bicycle*

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The stationary bicycle is a familiar apparatus found in most institutions where therapeutic exercise is prescribed. The indications for, and methods of, use of this modality in the treatment program are numerous and based primarily on empiricism. The stationary bicycle has been suggested as an apparatus to increase range of motion of the hip [5], knee, and ankle [3]; to strengthen muscles of the knee and ankle [1]; and to improve range of motion and strength of the extremity in general [2]. The universal acceptance of this exercise tool would seem to indicate a belief in its value for the patient with orthopaedic disabilities of the lower extremities, but to our knowledge the rationale of its therapeutic use has never been demonstrated experimentally.

The purpose of this paper is twofold: to correlate electromyographic observations of surface muscles thought to participate in exercise on a stationary bicycle with accompanying joint range studies, to evaluate the efficacy of some of the clinical methods in use.

MATERIAL AND METHODS

The subjects of the investigation were three healthy young adult women. Their height in inches was sixty-two, sixty-five, and sixty-seven; and weight in pounds 113, 102, and 130, respectively. All were active participants in sports and were experienced bicycle riders. One subject, J. A., well trained in laboratory procedures, performed six series of experiments. The other two were novices and performed one series each.

Each series of experiments consisted of the subject riding the bicycle with the seat at the lowest position (twenty-one inches from the center of the pedal sprocket) and then with the seat elevated four inches. Exercise in both positions was performed against no resistance and 1.5, three, four, 4.5, and five pounds of resistance. Some experiments were started with the seat high, others with the seat low. In all studies, the amount of resistance was increased in gradient steps from zero to maximum. The subject was instructed to cycle at an easy pace and to perform the activity as smoothly as possible, keeping the feet in the same position on the pedals throughout the series.

The stationary bicycle was typical of those found in many physical therapy centers (Fig. 1). The brake was applied by tightening a small hard cylinder against the back of the wheel. To repeat exactly the resistance against which the subject worked, a small fish scale was incorporated into the braking mechanism. A microswitch attached to the frame closed momentarily a three-volt dry-cell circuit as the foot pedal passed a given point. This activated an electromagnetic signal suspended above one channel of the electromyographic ink-writing Dynograph. The signal deflected the pen on the moving electromyogram thus indicating one cycle of the foot pedal.

Muscle-action potentials were picked up by skin electrodes and, after appropriate amplification, recorded on an eight-channel Offner Dynograph. Prior

* This work was supported in part by a grant from The Ford Foundation.

to each experiment, the electromyograph was calibrated with the same setting of amplification for all recordings and for all channels. The fourteen muscles sampled were: sacrospinalis, rectus abdominis (lower fibers), glutaeus maximus and glutaeus medius, tensor fasciae latae, sartorius, gracilis, rectus femoris, vastus medialis and vastus lateralis, semitendinosus, biceps femoris, medial gastrocnemius, and tibialis anterior. In a preliminary study, the semimembranosus and lateral gastrocnemius were also included. Because the activity in these two followed the same pattern as the semitendinosus and medial gastrocnemius, respectively, they were dropped for convenience of recording. The surface electrodes were Monel metal disks, one centimeter in diameter, with a hollow depression. They were placed equidistant from the motor point, previously determined by electrodiagnosis, with a minimal interelectrode space of 2.4 centimeters dis-

FIG. 1

Normal subject prepared to exercise on experimental stationary bicycle with seat elevated.

tance and on a line parallel with the muscle fibers. A mild erythema was produced by rubbing the skin of the selected areas with Microhm electrocardiograph jelly. The disks were filled with this substance and sealed in place with Aeroplast and adhesive tape. Simple range movements against resistance were performed to confirm correct electrode placement and preparation technique. With the exception of one experiment, all data were collected from the right extremity. In the control study, muscles were sampled from both limbs to confirm the supposition that the pattern of both extremities was identical except that the timing of muscle activity was reversed, that is, the extensor group on the right contracted in alternation with those on the left.

To reconstruct the postures assumed by the subjects under each condition

TABLE I

DEGREES OF JOINT RANGES OF MAXIMUM POSITIONS OF KNEE AND HIP MOTION COMPUTED FROM MOTION-PICTURE LINE DRAWINGS OF MULTIPLE CYCLES*

Subject	Height (*Inches*)	Hip			Knee		
		Flexion	Extension	Range	Flexion	Extension	Range
Seat 25 inches							
S.L.	62	55	30	25	99	39	60
J.A.	65	65	42	23	110	60	50
C.G.	67	67	40	27	100	45	55
Seat 21 inches							
S.L.		70	37	33	113	55	58
J.A.		77	40	37	117	75	42
C.G.		82	50	32	120	55	65

* Figures are given in terms of zero as complete hip or knee extension.

imposed, simultaneous motion pictures were made. The distance of the camera from the subject was identical for all experiments. Each motion picture frame was magnified by a Bolsey microfilm reader and the outline of the figure reproduced exactly as a line drawing.

Ninety-six different procedures yielding 1,920 electromyograms of pedal cycles were subjected to analysis. When the cycles were identical in time, as indicated by the pen deflexion on the electromyogram, the patterning of muscle action among subjects and under the various conditions prescribed were superimposed and compared by use of a view box. Over 1,000 frames of motion pictures were magnified and drawn for detailed study. The approximate center of the hip, knee, and ankle were marked; and, with the use of a protractor, the joint excursions were recorded. The sketches thus obtained were matched by use of the signal device with the electromyograms to facilitate analysis of movement and muscle action.

RESULTS AND THEIR INTERPRETATIONS

A comparison of joint ranges of the tallest and shortest subjects during bicycling is illustrated in Figure 2. These are outline drawings from motion pictures made during exercise with the seat at twenty-one and twenty-five inches from the center of the pedal sprocket.

With two fixed points—the seat and foot pedal—the relationship between the ranges of hip, knee, and ankle motion varied with the changing position of the extremity. The mechanical construction of the bicycle limited the distance through which the extremity moved with each circle of the pedals. During exercise against resistance, all subjects demonstrated maximum ranges of dorsiflexion and plantar flexion on the rotatory foot pedal. Maximum dorsiflexion occurred as the foot rolled the pedal into a position of maximum hip and knee flexion, while maximum plantar flexion occurred at the end of extension just as the extremity started into flexion. Maximum knee and hip extension occurred simultaneously in the cycle, neither reaching complete extension. From Position 2, Figure 2, the knee flexes to approximately Position 3, and the hip also begins to flex. Maximum knee flexion occurs at Position 4 slightly before maximum hip flexion. Hip flexion did not exceed 90 degrees, for the thigh, instead of continuing in flexion, internally rotated and adducted. Additional hip flexion would have caused an extremely unstable position of the pelvis because of the small supporting base offered by the seat and the extended position of the other extremity. A series of photographs made of a man, six feet tall, confirmed these observations, even though it was obvious that with the seat low the subject was too big for the instrument.

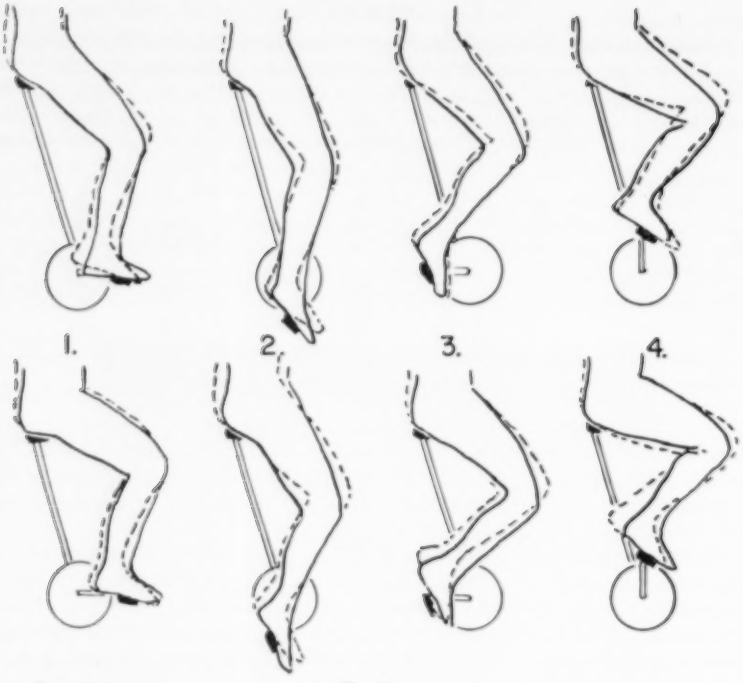

FIG. 2

Outline drawings from motion-picture frames of joint excursion in hip, knee, and ankle during one cycle. Height of subject, illustrated by broken lines, is sixty-seven inches; by solid lines, sixty-two inches. Above, seat elevated four inches; below, seat at lowest point.

A summary of the maximum excursions occurring in the hip and knee joints of all subjects is presented in Table I. The data represent the average of a large number of observations for any one subject. The only variations in the performance of the three subjects was seen in J. A. who invariably performed the exercise with the fore part of the foot rather than the instep on the foot pedal. The results of this position are reflected in greater flexion and less extension of the knee. Although the outside limits of maximum excursion in flexion and extension varied with the height of the subject, the differences between the two, representing the range, was fairly constant. It was possible to develop approximately 20 to 40 degrees of motion in the hip and from 40 to 65 degrees in the knee.

Electromyographic evidence presented in Figure 3 illustrates that the pattern of muscle-action potentials of the three subjects during exercise on the stationary bicycle was consistent. The resistance imposed here was three pounds. Pedaling against this amount of resistance was performed with ease and at an even rhythm by all subjects. The position of the pedals in Figure 1 indicates the deflection of the cycle marker pen. The duration of the cycle of subjects J. A. and S. L. was identical, that of C. G. being slightly shorter.

Electrical activity was minimal and variable in the sacrospinalis, rectus abdominis, glutaeus maximus, and glutaeus medius muscles. The activity of the tensor fasciae latae and sartorius preceded slightly that of the quadriceps group. The tensor fasciae latae and the sartorius probably assist in flexing the thigh. The tensor fasciae latae muscle may also counteract any tendency of the iliopsoas to cause external rotation. While it is unfortunate that this muscle is inaccessible to study by use of surface electrodes, it is reasonable to assume that the iliopsoas acts during hip flexion. Since the tensor fasciae latae and sartorius are both

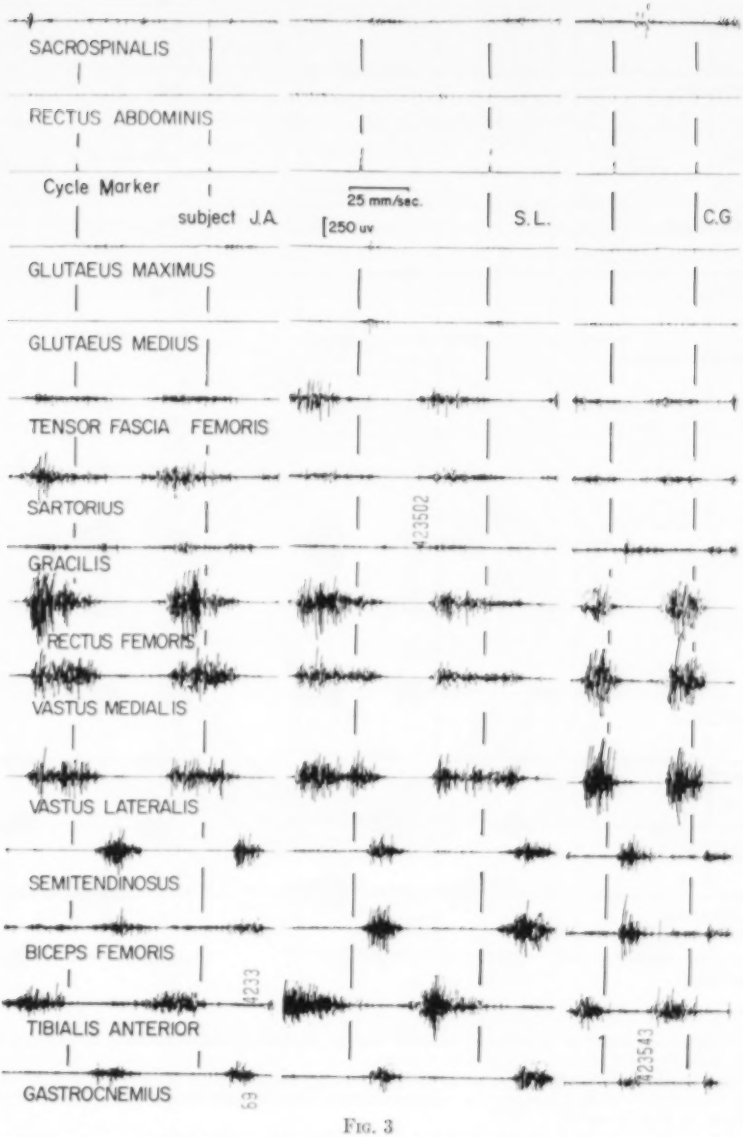

FIG. 3

Electromyograms of three subjects during exercise on a stationary bicycle against a resistance of three pounds (seat twenty-one inches). Deflection of cycle marker indicates position of right foot (Fig. 1).

flexors of the hip, and the latter of the knee also, their electrical activity during the extension phase of cycling, in conjunction with the quadriceps group, suggests that they stabilize the knee during strong extension. Duchenne demonstrated the tensing action of the sartorius on the femoral aponeurosis over the medial aspect of the thigh similar to that of the tensor fasciae latae on the lateral surface. This tensing lends support to the extensor force exerted through action of the quadriceps. The action potentials in the gracilis occurred during both quadriceps and hamstring electrical activity. Since the gracilis is an adductor of the hip and flexor of the knee, its action would hold the knee in mid-position when

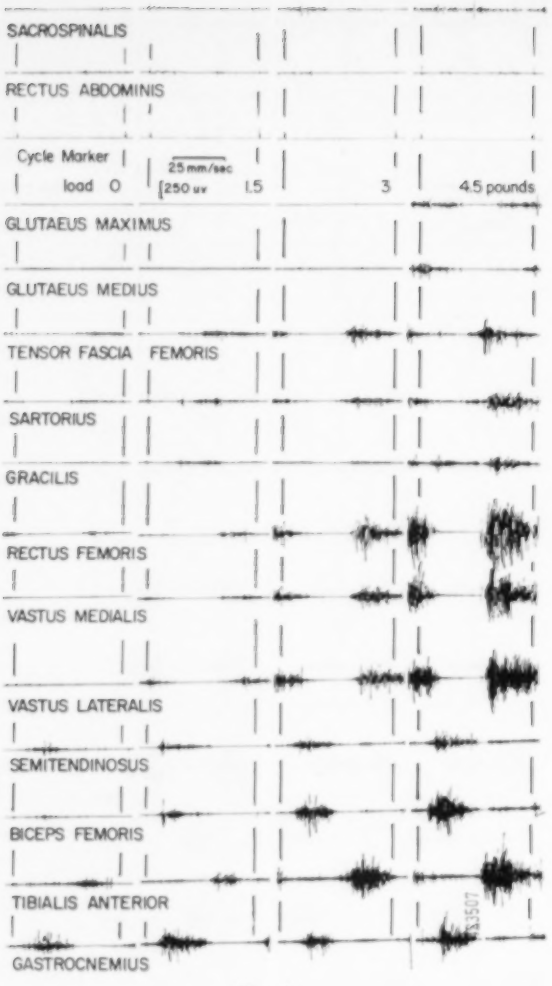

FIG. 4

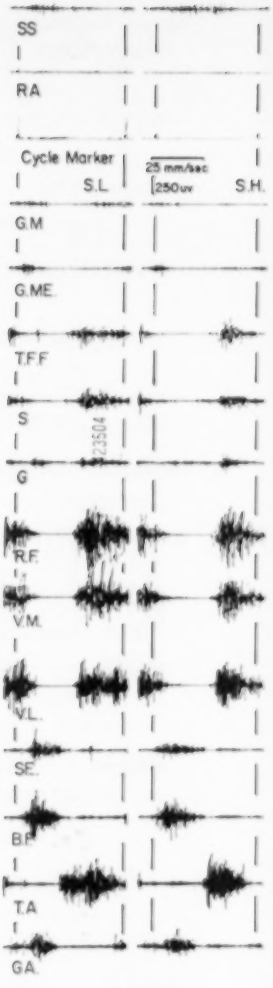

FIG. 5

Fig. 4: Changes in electrical activity of muscles due to increasing the resistance during cycling (seat twenty-five inches).

Fig. 5: Comparison of the muscle-action patterns during exercise with the bicycle seat at twenty-one (S.L.) and twenty-five (S.H.) inches. The resistance was four pounds. Order of muscles listed are the same as those in Figs. 3 and 4.

acting with the former and assist in flexion when contracting with the latter.

The timing of the action potentials recorded from the rectus femoris and vastus lateralis and vastus medius muscles was identical. The electrode was placed on the rectus femoris just proximal to the mid-thigh so that only activity from fibers concerned with action on the knee was recorded. The duration of contraction of these muscles was almost twice that of the hamstrings. The action pattern of the semitendinosus, semimembranosus, and biceps femoris was usually short in duration, building to a peak and then rapidly diminishing. The electrical activity occurred prior to cessation of the quadriceps and terminated before these muscles reactivated, that is, as the extremity approached maximum extension

and started into flexion. Under severe stress minimal activity occurred simultaneously with the quadriceps.

The tibialis anterior acted in conjunction with the tensor fasciae latae and sartorius. As the hip and knee approached maximum flexion the ankle dorsiflexed turning the pedal to a level position in preparation for the extensor thrust of the extremity. This contraction was maintained until the extremity was midway between maximum flexion and extension during the extensor thrust. Action potentials were evoked in the gastrocnemius at the terminal phases of extensor thrust when the ankle was strongly plantar flexed to assist the hamstrings in initiating flexion of the knee. The contraction phase of the gastrocnemius was relatively short in duration.

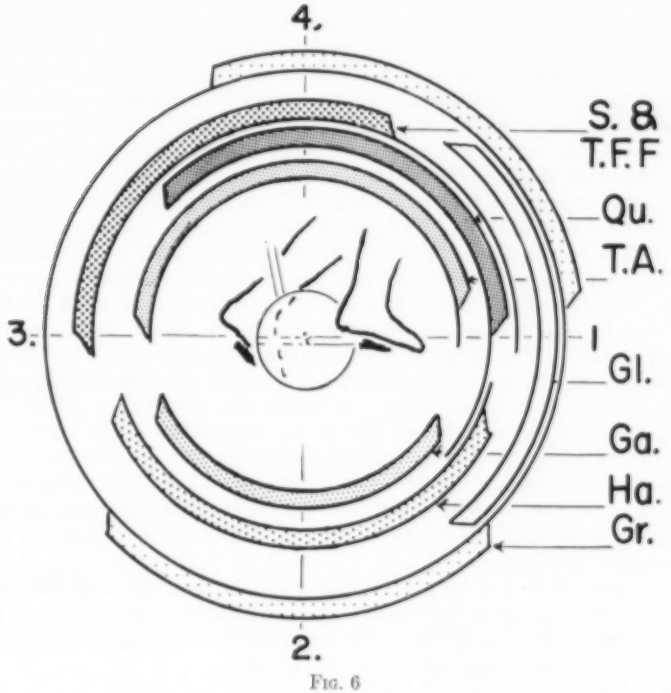

FIG. 6

Summary of muscle-action potentials during one cycle placed on a schematic time course. Greatest activity is confined within double lines, lesser activity continues as single line [Gr., gracilis; S. and T.F.F., sartorius and tensor fasciae femoris (tensor fasciae latae); Qu., quadriceps; T.A., tibialis anterior; Gl., glutaeus maximus and medius; Ga., gastrocnemius; Ha., hamstrings].

The effect of increasing the resistance against which the subject is pushing the pedals is illustrated in the electromyograms in Figure 4. When no brake was applied action potentials occurred primarily in the gastrocnemius and tibialis anterior. Unpublished experiments conducted on other muscles of the foot and ankle demonstrated that these other muscles also participated. Bicycling as rapidly as possible against no resistance increased the electrical activity and the number of muscles participating in the exercise. The magnitude of the electrical activity resulting from this rapid pedaling, however, was not as great as that obtained through loading. The number of muscles contracting and the magnitude of action potentials produced increased with added resistance. Even though the resistance became so great that the subject required assistance to initiate the movement, incoordination was never evident. The pattern of action of each muscle remained discrete in its timing.

Changing the height of the bicycle seat did not influence the pattern of muscle action (Fig. 5). In the majority of records the magnitude of the muscle-action potentials was less when pedaling with the seat high than when pedaling with the seat low against the same resistance. The relative ease with which the subjects pedaled against heavy resistance in the former position was obvious to both operator and subjects. In several instances, exercise against five pounds could be performed when the seat was elevated the four inches, but not otherwise.

The schematic diagram (Fig. 5) was reconstructed from the analysis of all the electromyograms recorded during cycling against resistance. Since this is a bilateral exercise, reciprocal in nature, movement and muscle-action potentials of both extremities must be considered. Either the right or left tensor fasciae latae, sartorius, and quadriceps group were in a state of contraction continuously. One side started to act before the other ceased. This was not true of the hamstring and gastrocnemius groups. The action potentials evoked in the sacrospinalis, rectus abdominis, and two gluteal muscles were so minimal that they could be excluded as significant participants in this activity. The electromyograms indicated that exercise on a stationary bicycle involved primarily the hip flexors, the knee extensors, and the muscles acting on the foot and ankle.

A study of the motion pictures demonstrated that with loads requiring severe effort, the subject rotated the trunk toward the side of the extremity which was in extreme flexion, but as this limb proceeded downward through the extension range, rotation of the trunk to the opposite side occurred. The activity of the trunk was jerky and uncoordinated with pauses at maximum flexion and at full extension. Inability of the subject to continue cycling occurred when the extensor force of one leg did not create sufficient momentum in the final phase of the downward stroke of the pedal to continue the revolution, with the result that the hamstrings and gastrocnemius could not contract strongly enough to initiate the knee flexion which takes place just before the opposite extremity reached the position for its extensor thrust. The strong contraction of the knee extensors and hip flexors acting in alternation precluded the need for hip extension and minimized knee flexion action. Professional bicycle riders use a strap across the toes to obtain a pulling action during the flexion phase in combination with the extension phase on the contralateral extremity. This may be considered of value in some clinical applications.

The constancy of the pattern of muscle action indicates that the bicycle is important as an apparatus for improving coordination. This device, if used in conjunction with electromyography, may be useful in studying patterns of muscle action in patients with neuromuscular disorders.

SUMMARY

Multiple lead electromyograms were recorded simultaneously with motion-picture studies of normal subjects during exercise on a stationary bicycle. Action potentials were picked up by surface electrodes from the sacrospinalis, rectus abdominis, glutaeus maximus and glutaeus medius, tensor fasciae latae, sartorius, gracilis, rectus femoris, vastus medialis, vastus lateralis, semitendinosus, biceps femoris, tibialis anterior, and gastrocnemius. Bicycling was performed against resistance of varying degree with the seat twenty-one and twenty-five inches from the center of the pedal sprocket. The evidence presented supports the following conclusions:

1. During bicycling, muscles contract in a pattern which is orderly and coordinated. This was unchanged even when the resistance was so great that assistance was needed to help initiate rotation of the pedals.

2. The pattern muscle activity is highly reproducible in each individual subject and among the three different subjects under test.

3. Varying the height of the bicycle seat does not influence, in general, the

timing of muscle activity, but the exercise is performed with less effort when the seat is high.

4. As the resistance to muscle action increases, electrical activity intensifies in each muscle and develops in other muscles. Exercise against no resistance evokes action potentials primarily in the muscles acting on the foot and ankle.

5. The bicycle is a useful therapeutic device for increasing the range of motion in the hip, knee, and ankle within certain limits. The ankle moves through its complete range of motion, while considerably less motion occurs in the knee, and still less in the hip.

6. Of the muscles studied, those most necessary for pedaling a stationary bicycle are the tensor fasciae latae, sartorius, quadriceps femoris, and tibialis anterior as demonstrated by multiple lead electromyography.

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Bucket-Handle Tear of Acetabular Labrum Accompanying Posterior Dislocation of the Hip

BY THOMAS B. DAMERON, JR., M.D., RALEIGH, NORTH CAROLINA

Posterior dislocation of the hip, unassociated with a fracture, is not usually difficult to reduce if there is adequate relaxation from anaesthesia. When the acetabular labrum is torn and caught between the femoral head and acetabulum, satisfactory closed reduction is impossible.

When a femoral head dislocates posteriorly, it must go through a defect in the capsule between the cartilaginous labrum and the acetabulum or through the bony posterior portion of the acetabulum. When the cartilaginous labrum is separated from the acetabulum by the femoral head, it may be displaced in a manner similar to a bucket-handle tear in a knee meniscus. If the femoral head brings the torn cartilage ahead of it into the acetabulum as it is being reduced, a derangement occurs which prevents anatomical reduction and necessitates surgical intervention.

R.E.W., a white male, thirty years old, was brought to the emergency room on May 18, 1957, after having been injured in an automobile accident. Roentgenograms of his pelvis (Fig. 1) revealed that the right hip was dislocated posteriorly. The hip was manipulated under spinal anaesthesia. It was noticed that, as the femoral head was replaced in the acetabulum, there was

FIG. 1

Posterosuperior dislocation of right hip.

not the usual clunking sound. Furthermore, the hip was relatively unstable and redislocated when flexed to 45 degrees. Roentgenograms made after manipulation revealed that the femoral head was opposite the acetabulum but that the joint space was wider on the right side (Fig. 2). It was difficult to get a satisfactory lateral roentgenogram because of the discomfort of the patient and instability of the hip. The femoral head was opposite the acetabulum but was not well seated. Soft-tissue interposition was suspected and operation was performed May 21, 1957.

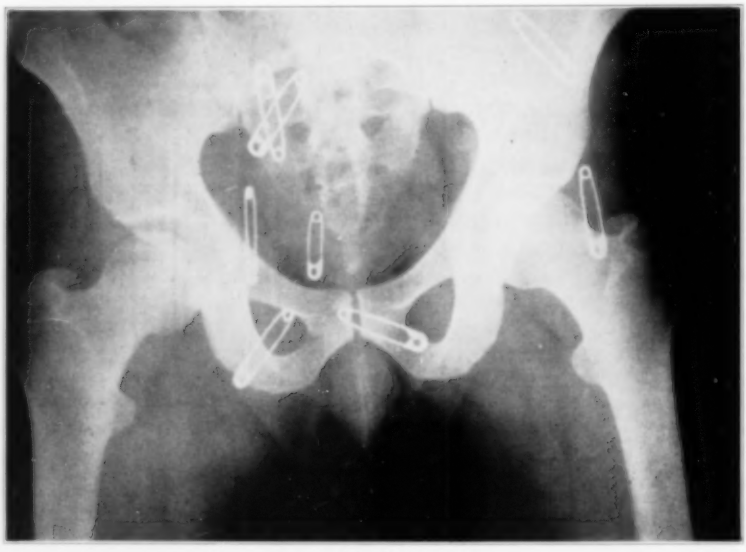

FIG. 2

Roentgenogram made after manipulation. The joint space is wider than on the unaffected side.

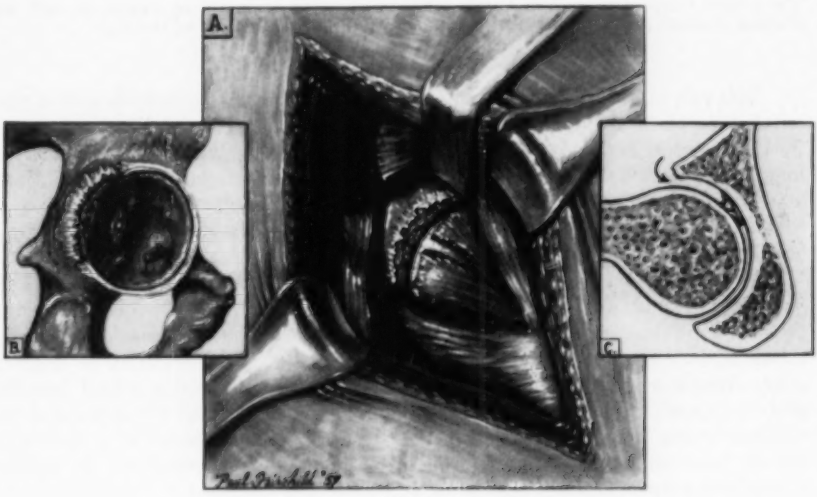

FIG. 3

Fig. 3, *A*: Osborne incision of right hip showing the split glutaeus maximus muscle. The piriformis muscle is retracted superiorly. The T-shaped rent in the capsule is lateral to the sciatic nerve.

Figs. 3, *B* and 3, *C*: Involution of the glenoid labrum and periosteum.

The hip was approached through a posterior Osborne incision (Fig. 4). A T-shaped tear was seen in the capsule. The hip redislocated posteriorly easily. With strong traction on the femur, the cartilaginous labrum could be seen within the joint. It was pulled out to its normal position with a blunt hook. Two holes were then drilled into the acetabulum, and the cartilaginous labrum was sewn to the bone with chromic catgut sutures. After this was done, the hip was stable beyond 90 degrees of flexion. Buck's traction was applied postoperatively. On the second postoperative night, disorientation caused the patient to remove the traction and get out of bed. This action had no apparent harmful effect on the hip. He was allowed to walk with crutches after three weeks, and began full weight-bearing after six weeks (Fig. 4).

FIG. 4

Roentgenogram of pelvis after patient had begun weight-bearing.

The patient returned to work in August 1957 and when last examined on August 23, 1958, was working regularly. He had very little pain and a full range of motion of the hip.

COMMENT

The role of an intervening acetabular labrum preventing reduction of a posterior dislocation of the hip has not been recorded in the English literature except for the report of Paterson. Incarceration of a bone fragment in the acetabulum has long been recognized. It is seldom overlooked on roentgenographic examinations. There is unanimity in recommending operative treatment for this condition. A torn acetabular labrum incarcerated between the joint surfaces is more difficult to diagnose and unless specifically looked for may go untreated.

Paterson stated that in his patient with soft-tissue interposition (Case I), the hip was quite stable. Apparently the hip is less stable if the femoral head does not seat fully into the acetabulum due to a defect in the posterior buttress of the acetabulum, for the patient's hip redislocated when flexed to more than 45 degrees. After dislocating in this position the femoral head could be brought back into the acetabulum with ease, but the clunk which is characteristic of the dislocated hip was not heard. When this clunk is not heard during the reduction of a dislocated hip an intervening torn acetabular labrum should be suspected and an anteroposterior roentgenogram of the pelvis and both hips obtained.

A difference in the width of the joint spaces suggests soft-tissue interposition. At surgery when the labrum was reattached it seemed to serve a useful purpose in preventing redislocation of the femur. On the second postoperative night this patient sat up, got out of bed, and walked, with no apparent harm to the hip. Although Paterson excised the torn labrum, I feel that this strong structure has an important function and should be replaced if possible.

SUMMARY

A tear of the acetabular labrum with interposition following the reduction of posterior dislocation of the hip should be suspected when: (1) the femoral head does not clunk into the acetabulum at the time of the reduction, (2) the hip is unstable after manipulation even though there is no fracture, and (3) the roentgenograms of the pelvis show the femoral head to be resting further from the acetabulum on the affected side than on the non-affected side. The fibrocartilaginous labrum should be reattached to the acetabulum.

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Coxa Plana, Its Genetic Aspects and Results of Treatment with the Long Taylor Walking Caliper

A Long-Term Follow-up Study * †

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About 1909, the clinical application of the x-ray allowed Legg in America, Calvé in France, and Perthes in Germany to distinguish from tuberculosis of the hip a new syndrome which commonly bears their name. Waldenström of Sweden, another pioneer investigator, named it coxa plana and this describes well the deformity that will usually evolve if the anomaly is left untreated. In the present study, the patients treated for coxa plana prior to 1950 at the Hospital for Sick Children, Toronto, have been re-assessed. Of the 212 recorded cases, it has been possible to trace, question, and re-examine clinically and roentgenographically, 129 patients (Table I).

TABLE I

Review of 234 Cases Indexed as Coxa Plana

		No. of Cases
Included in study		
	Examined and x-rayed	129
Excluded from study		
	Untraced	44
	Traced, but not seen	36
	Deceased	3
	Total cases, coxa plana	212
Not coxa plana		
	Following congenital dislocation	10
	Following fracture or dislocation	4
	Slipped upper femoral epiphysis	3
	Osteochondritis	3
	Following osteomyelitis	1
	Gaucher's disease	1

The earliest case of coxa plana that the Hospital for Sick Children has on record was treated in 1917, and the longest period of follow-up is about twenty-six years (Table II). Some over-all clinical features were: (1) 105 male patients and twenty-four female, (2) twenty-three patients with bilateral disease, and

*This study was initiated and directed by Dr. R. M. Wansbrough. His untimely death in May 1956 makes the completion and publication of the results of his study a memorial to his lifelong interest in this disease.

†This work was supported by funds granted by the Province of Ontario, under the National Health Grants Programme of the Department of National Health and Welfare, Ottawa, Ontario, Canada. A preliminary report on this study was made to The Canadian Orthopaedic Association in June 1955.

(3) twelve patients with family history of coxa plana. Our cases adhered to the classic clinical picture; the ratio of incidence was four boys to one girl, onset occurred usually between the ages of four and nine, and symptoms started with a limp followed by pain in the hip, or, less frequently, in the knee (Table III). Examination in the early stages showed spasm of the muscles about the hip, with limitation of internal and external rotation, and of abduction, together with atrophy of the thigh and calf. The roentgenographic changes throughout the course

TABLE II

TIME FROM ONSET OF SYMPTOMS AND FROM COMPLETION OF TREATMENT TO RE-EXAMINATION

Period of Follow-up (Years)	From Onset of Symptoms (No. of Cases)	From Completion of Treatment (No. of Cases)
5 to 10	55	60
10 to 15	27	29
15 to 20	15	13
Over 20	32	27

of the disease suggest an initial necrosis of the femoral head in part or in whole, followed by resorption of the dead bone, and almost simultaneous replacement with new bone (Figs. 1-A through 1-F). In addition to the classic early signs of increased density of the head of the femur, metaphyseal cavitation, and lateral metaphyseal erosion, we observed subarticular lines of decalcification. The diagnosis should not depend on flattening of the head or fragmentation. As our pa-

TABLE III

SYMPTOMS PRESENT WHEN TREATMENT WAS SOUGHT

Symptoms	No. of Cases
Limp	50
Limp and hip pain	46
Limp and knee pain	11
Hip pain	10
Knee pain	4
Miscellaneous	8

tients were treated by non-operative methods, we can add nothing to what is already known of the pathological changes in the bone [4,10,18,28].

The present study supports the current belief that coxa plana is a disease of constitutional origin and not due to local infection or injury of the hip. Minor injuries and systemic infection may, however, precipitate this disease. Hospital records show that in fifty-eight cases there was no precipitating factor; in forty-seven there was minor trauma; in six, moderate trauma; in fifteen, infection; and in three, there was no information.

Twelve of our patients had relatives who are known to have had coxa plana, and a further seven have unexamined relatives with a limp or hip trouble of unknown etiology. In genetic terms, from an analysis of the sibs born subsequent to 124 probands in our pedigrees, the frequency of the occurrence of coxa plana was found to be one in thirty-five. Compared with the incidence in the general population of one in 20,000, the difference is highly significant. The pat-

tern of inheritance based on the present pedigrees was found by Ruckerbauer to be a sex-influenced, autosomal dominant with reduced penetrance and varying expression. Statistical analysis did not support a recessive mode of inheritance.

Goff [15] found a family history of the disease in 20 per cent of the cases he studied, and Stephens and Kerby [33] were able to trace this disease through five generations in one family, finding twenty-eight cases in the sixty-three children examined. The bilateral occurrence of the condition also points to a constitutional origin. The disease was bilateral in 20 per cent of our patients, including monozygotic male twins, each with bilateral coxa plana [36]. A recent paper of Ponseti [28] suggested that the basic defect may be in the epiphyseal plate.

Thyroid dysfunction has been suggested by many as a factor in coxa plana, but this has been disproved more convincingly than it has been proved [1,5,7,14]. There is nothing in the present study to suggest that excess fluorine is a factor in the disease.

General agreement is lacking as to what is the best treatment for coxa plana. Legg [21] felt that the disease ran a self-limiting course, and Sundt [34] supported him in this view. However, Danforth [6] and later Eyre-Brook [8] recognized that if weight-bearing could be prevented, flattening and broadening of the femoral head and neck would be greatly reduced, and if this treatment could be started early in the course of the disease, a nearly normal anatomical reconstitution of the femoral head would be obtained. Since prevention of deformity of the femoral head would seem to give the best guarantee against subsequent arthritis, accepted treatment has been directed mainly to prevent weight-bearing. While it would seem that simple bed-rest would achieve this satisfactorily, few children can be kept from getting up on their hands and knees, or from slipping out of bed when they are not watched. Because of these difficulties, special splints were employed by Pike [27] and Goff [15] for use in bed. These require supervision, usually with hospitalization of the patient, for up to three years, thus interfering with the educational and social development of the child. The cost of such hospitalization can amount to several thousand dollars.

In order to overcome these latter criticisms, orthopaedic surgeons have used different methods of ambulation without weight-bearing on the affected extremity either as the entire treatment, or to supplement an initial period of complete bed-rest. Until 1930, the Hospital for Sick Children used a Thomas type of caliper; but, as this did not prove satisfactory, a Taylor type of caliper, with a high shoe on the normal side, was then used for the majority of patients. For those with unilateral coxa plana, this splint is used throughout the course of the disease, and for bilateral, after a period of bed-rest has allowed one hip to heal sufficiently to bear weight (Figs. 2-A and 2-B). The importance of careful home supervision of the child in his brace is emphasized to the parents, and the child is re-examined at three-month intervals to make certain the brace is in good repair and that the child is not scuffing his shoes. In this splint, the weight is transmitted to the caliper from the ischial tuberosities by means of straps which pass under the latter from a bar around the waist. If the child loosens the straps to allow his foot to touch the ground, the upper bar catches him under the armpits, making the splint most uncomfortable. Special stools have been constructed with the seat fashioned like a bicycle seat to allow the child to sit without removing the brace. Using this stool, the child is able to attend classes at school. Because of the frequent later involvement of the second side, the course of the disease is followed by roentgenograms made to show both hips. Lateral views are necessary to judge the degree of bone regeneration, and these are made with the child in the frog-leg position. The splint is usually worn until regeneration is complete.

In order to compare the end results of our treatment by the Taylor caliper with the results of other centers and methods, our cases have been divided into excellent, good, fair, and poor results by the two most commonly used methods

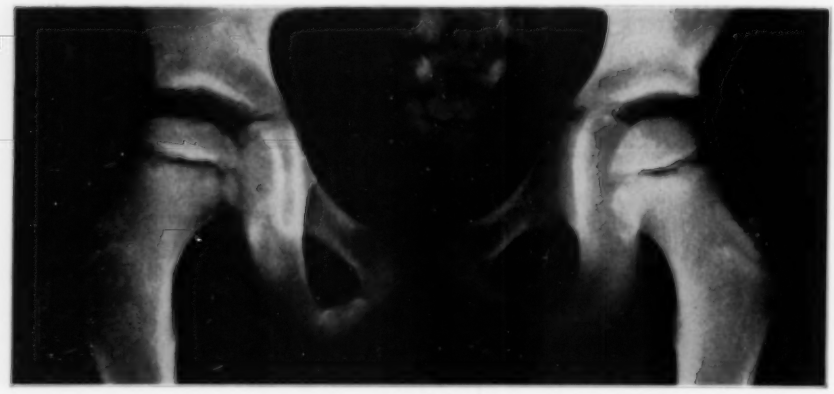

FIG. 1-A

Figs. 1-A through 1-F: Patient M. B. Roentgenograms showing changes from onset of coxa plana through follow-up.

Fig. 1-A: Condensation.

FIG. 1-B

Fragmentation.

FIG. 1-C

Regeneration.

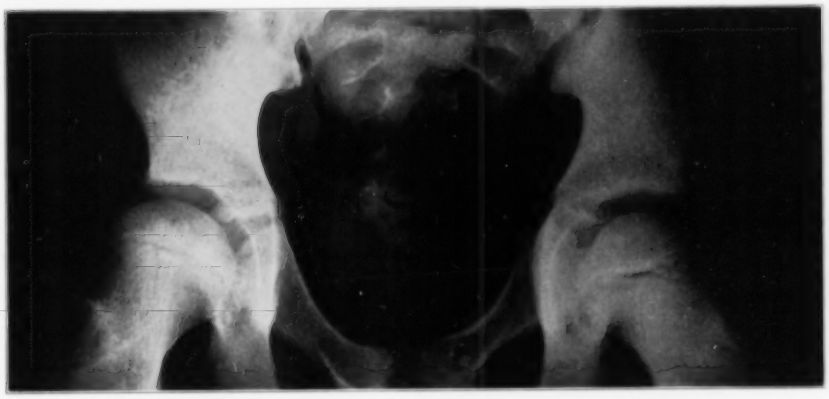

FIG. 1-D
At completion of treatment.

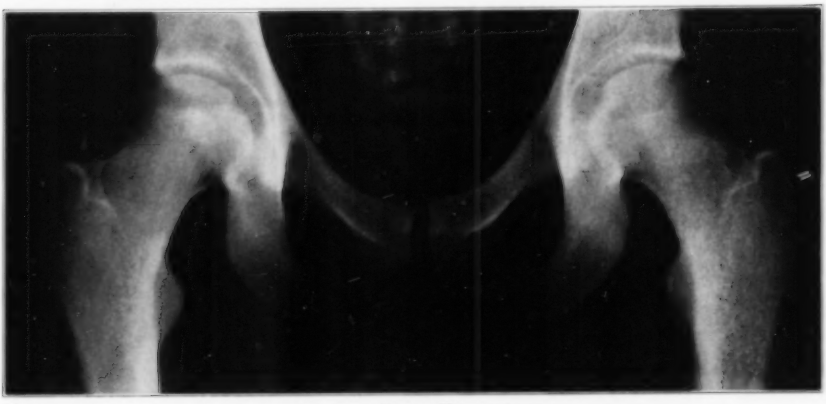

FIG. 1-E
Twelve years after treatment.

FIG. 1-F
Twelve years after treatment.

FIG. 2-A

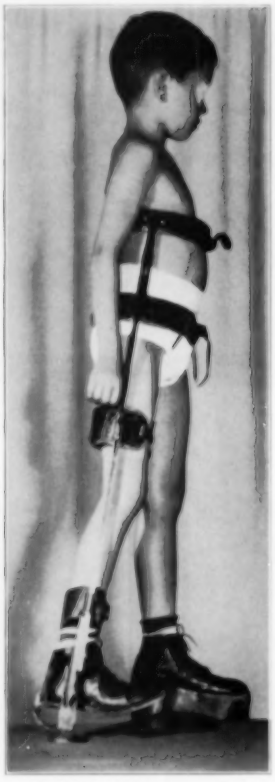

FIG. 2-B

Long Taylor walking caliper used at the Hospital for Sick Children.

of classification. The first method is the comprehensive quotient of Heyman and Herndon [20] which measures only the anatomical deformity of the femoral head, neck, and acetabulum. The second is the method of Levy and Girard [22] which takes into consideration the presence or absence of pain, and the degree of limitation of movement, and of shortening of the affected extremity, as well as the deformity of the femoral head. It is interesting to note that in 88 per cent of our cases the patients are similarly divided into excellent, good, fair, and poor results by the two methods. Both the degree of restriction of movement and the amount of shortening parallel the anatomical deformity of the femoral head. It is unfortunate that in nearly every reviewed series, the author has devised his own method of assessing end results, thus making over-all comparisons difficult. Two other factors make comparison of different series difficult, one being the age of the patient at the onset of the disease, and the other the stage to which the disease has advanced when treatment is started. The effect of the age of the patient on the end result is illustrated in Charts I and II. Only excellent and good results were obtained in children under the age of five, while no excellent results were obtained in those over ten.

The stage to which the disease has advanced when treatment is started has an equally striking effect on the end result, for no form of treatment, available at the time of writing, will correct a flattened femoral head and broadened femoral neck, if these are present at the start of treatment. The duration of symptoms, clinically, does not always indicate the stage to which the disease has progressed as shown by roentgenograms (Table IV).

TABLE IV

RELATION BETWEEN THE DURATION OF SYMPTOMS AND THE STATUS OF THE DISEASE WHEN FIRST SEEN IN ROENTGENOGRAMS

Duration of Symptoms (Months)	Stage of Disease as Seen by Roentgenograms: Very Early (No. of Patients)	Early (No. of Patients)	Advanced (No. of Patients)	Very Advanced (No. of Patients)
Less than one	11	7	3	1
Two to three	6	18	7	0
Four to six	1	8	8	0
More than seven	1	7	17	11

Thus it must be realized that a comparison of different series of cases is valid only if they can be shown to have the same age distribution relative to diagnosis of early, moderately advanced, and advanced cases. Nevertheless, a general comparison of the various reported series of cases (Table V) certainly

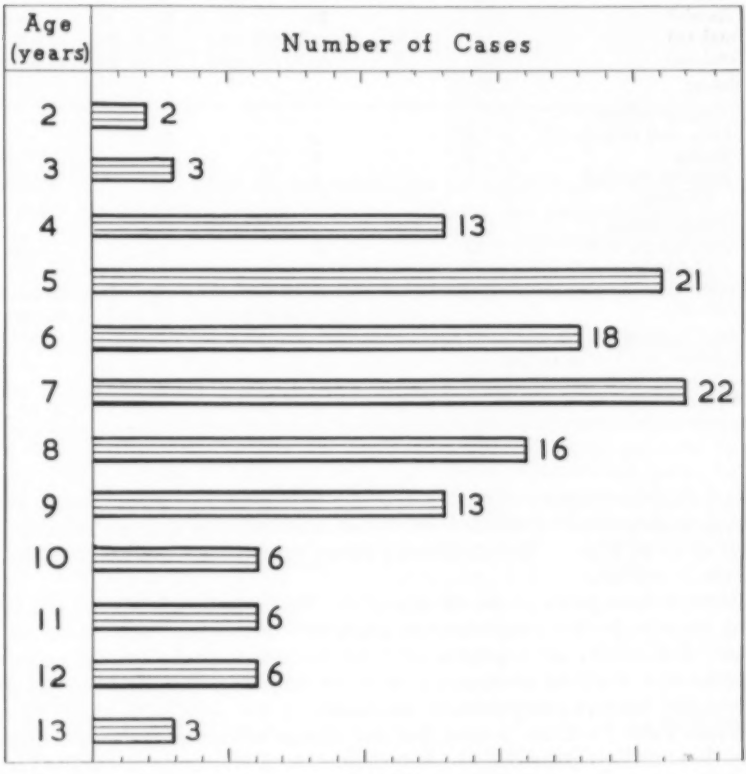

CHART I

Age distribution at onset of coxa plana.

TABLE V

CORRELATION OF END RESULT WITH TREATMENT USED IN DIFFERENT SERIES REPORTED IN THE LITERATURE

Treatment	Excellent (*No. of Patients*)	Good (*No. of Patients*)	Fair (*No. of Patients*)	Poor (*No. of Patients*)
None				
Levy and Girard	0	3	4	9
Mindell and Sherman		3	1	
Broder	0	2	3	1
Ratliff		1	4	4
Hospital for Sick Children	0	0	6	5
Total		E + G = 16 per cent	F + P = 84 per cent	
Non-ambulatory				
(a) Bed-rest or plaster				
Mindell and Sherman				
Early		14	3	1
Late		1	1	5
Broder	12	17	15	6
Hospital for Sick Children	4	3	5	2
(b) Bed-rest with splints or traction				
Goff	10	14	3	1
Ratcliff		18	15	8
Total (a)		E + G = 57 per cent	F + P = 43 per cent	
Total (b)		E + G = 60 per cent	F + P = 40 per cent	
Ambulatory				
(a) Thomas caliper				
Levy and Girard	2	2	10	7
Broder	2	3	1	0
Hospital for Sick Children	1	3	8	4
(b) Taylor caliper				
Hospital for Sick Children	32	25	9	10
Total (a)		E + G = 30 per cent	F + P = 70 per cent	
Total (b)		E + G = 75 per cent	F + P = 25 per cent	
Combined bed-rest with later ambulation in Thomas caliper				
Herndon and Heyman	12	21	4	4
Total		E + G = 80 per cent	F + P = 20 per cent	

shows that the prevention of weight-bearing, by any means, gives a much better result than that obtained without treatment, and indicates that ambulation in a long Taylor walking caliper produces just as satisfactory results as prolonged bed-rest in splints.

More definite proof of the efficacy of the Taylor caliper is given by a study of the changes in the comprehensive quotient[20] throughout the course of the disease (Table VI). As a general rule, in the satisfactorily treated cases, the comprehensive quotient remains the same, or improves, from the time of diagnosis to the time of completion of treatment.

From Table VI it can be seen that any change in the comprehensive quotient in the five to fifteen-year period after completion of treatment is usually for the better. In cases diagnosed early, a period of about twenty-eight months is required for complete regeneration of the femoral head. If the disease is not

TABLE VI

CHANGES IN THE COMPREHENSIVE QUOTIENT DURING TREATMENT OF COXA PLANA IN THE LONG TAYLOR WALKING CALIPER. SUMMARY OF TWENTY-FIVE CASES

Patient	At Onset (Per cent)	At End of Treatment (Per cent)	After Years of Follow-up 5 (Per cent)	10 (Per cent)	15 (Per cent)	20 (Per cent)
S.B.	93	88	95			
M.B.	91	85			100	
G.B.	95	84		89		
G.C.	79	79		88		
M.C.	83	79		78		
E.C.	86	86		90		
H.D.	95	75			75	
L.D.	96	91	93			
B.F.	99	82			88	
D.F.	93	71		70		
R.G.	90	69			68	
B.G.	89	73		81		
J.G.	81	87		89		
D.G.	93	77		80		
W.H.	100	96		95		
G.H.	96	85		93		
H.H.	84	74	85			
N.H.	87	86		86		
R.H.	91	70		73		
J.J.	80	84		84		
R.M.	89	92		92		
L.M.	91	86			97	
S.M.	89	93		90		
B.O.	89	99		99		

diagnosed until the stage of fragmentation or early regeneration, three to five years are required. In the majority of cases the comprehensive quotient at the time of follow-up, five to twenty years later, approximates very closely that at the start of treatment, and shows that the treatment achieved its purpose; it prevented further flattening and deformity of the femoral head and neck during the period of reabsorption and healing.

Since this treatment has given such good results in a majority of the patients, the use of the long Taylor walking caliper would seem to be the method of choice in patients with unilateral disease, and in those with bilateral disease after a period of bed-rest has allowed one side to heal sufficiently to bear weight. Thus a further examination of the failures in this group of patients treated by the Taylor caliper is indicated to see if further improvement could be obtained. Of the twenty patients with poor and fair results, the disease was far advanced in twelve when treatment was started. There are, thus, eight patients with an unexplained fair or poor result; poor cooperation would seem to be the major cause of failure in these. This is, of course, a failure in the method of treatment, and probably indicates that if progressive flattening of the head is seen as the child is followed by roentgenograms at three-month intervals, sterner methods must be taken to secure cooperation. Greater surveillance is possible when the child is treated in a hopsital, in braces or casts, but it is doubtful if any method of treatment can guarantee an excellent result if the child is determined to bear weight on the affected limb.

The recent work of Harris and Hobson [17] with rabbits suggested that penetration of the epiphyseal plate and curettage might hasten regeneration in the older child with slow healing. We have had no experience with drilling, and the

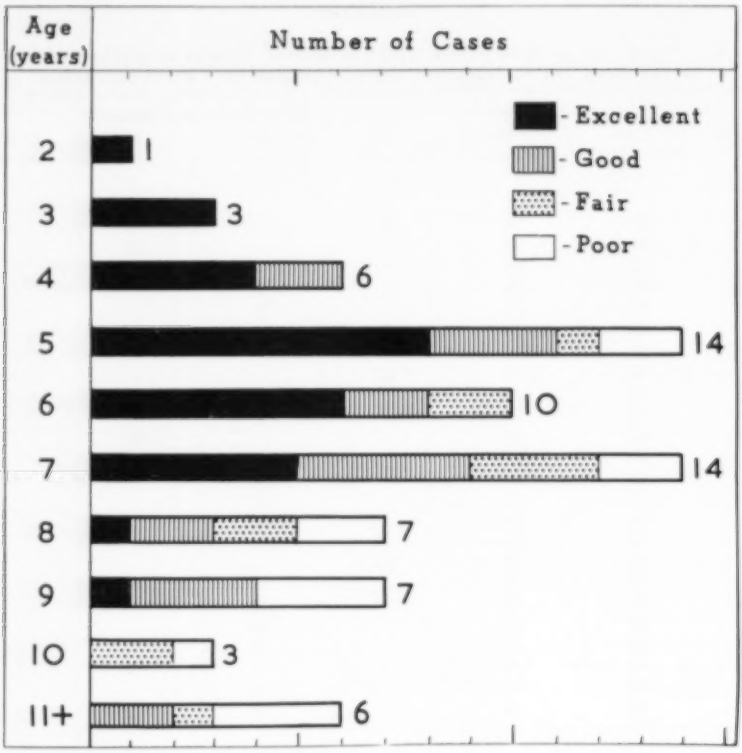

CHART II

The effect of age in those patients treated in the Taylor caliper.

reported results of drilling[32] do not appear to be as satisfactory as those obtained by conservative methods. This might well be due to failure to prevent weight-bearing after drilling until complete regeneration has occurred; the use of a Taylor caliper after operation might improve the results of this procedure.

While there is some shortening of the affected lower extremity at the completion of treatment, due to disuse, the amount of shortening that persists into adult life parallels the deformity of the femoral head. In the group of patients with excellent results who were treated by the Taylor caliper, the average shortening was less than one-quarter of an inch; in those with good results, between one-quarter and one-half of an inch; in those with fair results, about five-eighths of an inch; and in those with poor results, about three-quarters of an inch. Two patients did not adhere to this, showing shortening of one inch or more with a well re-formed femoral head. One child wore braces for five years, and was left with one and one-quarter inches shortening and a comprehensive quotient of 80 per cent. Another child still had one and one-quarter inches shortening two years after completion of treatment at the age of twelve, but may still regain length.

Eight patients were treated by sling and crutches. These showed considerable shortening at the end of treatment with an average of about one inch. This group of eight had either good or excellent regeneration of the head and neck of the femur; the shortening took place in the leg bones. Most of these are regaining length with the passage of time, but one still showed one and one-quarter inches shortening four years after completion of treatment at the age of thirteen.

A study of the patients with bilateral disease provides some observations of interest. As a general rule the second side is recognized earlier, treated sooner, requires less time to heal, and has less residual deformity than the first side. The disease does not usually begin on both sides simultaneously, changes becoming evident in the second hip from six months to two and a half years after the first. As the disease is bilateral in 10 to 20 per cent of the patients, it is important to make roentgenograms of both hips in following the course of the disease.

In assessing the end result in the 129 patients variously treated, we have been impressed by the fact that even when there is marked residual deformity of the femoral head, the patient is often able to continue well into middle life without serious disability. One patient, a thirty-seven-year-old man, was a foreman in a city water department. He has to climb in and out of trenches, and does so without pain in his hip. After a hard day's work, however, he noticed a little limp. In the 129 cases, hip fusion was necessary in one for relief of pain; in another, an arthroplasty of the hip was done; and, in a further five, there was enough disability to interfere with their work. It is a general observation that the older the child at the time of onset, the poorer the prognosis; in three of the five patients with disability the disease developed after the age of ten. A study of the patients who reached the fifth, sixth, or seventh decade of life will be required to determine the true incidence of osteo-arthritis. We studied, roentgenographically, the hips of a patient with coxa plana, and those of his father, and paternal grandfather. Both the father and grandfather had had trouble with their hips since childhood—very likely the same condition. At the time the roentgenograms were made the grandfather had disabling arthritis. When these deformed femoral heads are compared with those resulting from adequate treatment it can be seen that proper care may eliminate the anatomical deformity which leads so often to arthritis.

SUMMARY AND CONCLUSIONS

Follow-up studies from five to twenty-six years were made of 129 patients with coxa plana. The patients were treated mainly by ambulation in splints which prevented weight-bearing on the affected hip. This study suggests that the long Taylor walking caliper will prevent deformity of the femoral head just as well as the more drastic methods of bed-rest in splints. The Taylor caliper is a better method of treatment than sling and crutches, as the latter seems to lead to considerable limb-length discrepancy. Since the Taylor caliper allows the child to remain with his parents and to continue his social and educational development, we believe it is the treatment of choice in patients with unilateral disease throughout the course of the disease, and in those with bilateral disease after a period of bed-rest has allowed one hip to heal sufficiently to bear weight.

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Treatment of Tennis Elbow (Epicondylitis) by Denervation

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The syndrome known as tennis elbow, or epicondylitis, presents three essential characteristics. There is persistent and sometimes intense pain over the lateral and posterior aspects of the radial epicondyle, there is pain on extension of the wrist and thumb, and weakness of hand grasp.

The pathological changes associated with this triad of symptoms are unknown. The treatment is beset by frequent failures, as testified by the great variety of methods of treatment which have been suggested.

In order to find the reason for the persistent pain and in the hope of finding a more successful method of treatment, an investigation was undertaken by the author. This consisted in anatomical dissections of the region with the intention of establishing whether the peculiarities of local structures could be responsible for the pain.

The nerve distribution to the lateral aspect of the elbow was considered a possible factor responsible for the symptoms. The investigation was, therefore, concentrated on the character of the nerve supply of this region. According to Hilton's law, articular branches are supplied by nerves which contribute to the muscles moving the corresponding joint.

A personal investigation of the nerve supply of the lateral aspect of the elbow joint confirmed the findings of Gardner and his collaborators [1,2,3] and of other investigators [5,6,7]. It also permitted the addition of a few details as to the variability of the nerve supply. Important additional information was obtained from recent investigations by Stilwell who described nerve distribution in tendons, aponeuroses, and fasciae and their termination. He found proprioceptive endings in the aponeuroses and especially in retinacula suggesting the possibility of kinesthetic function of these nerve endings.

The classic investigations of Gardner pertaining to the nerve supply of joints in general have indicated the complexity of the problem of articular pain. Minute nerves are distributed along the arterioles which penetrate the capsules of the joints. There are in addition a variety of nerve endings in the periarticular structures.

Although the actual pathology of epicondylitis is not known, it is suspected that the pain and weakness are associated with the complex nerve distribution of the region and might, perhaps, be due to some irritating factor affecting these nerves.

ANATOMY OF NERVE SUPPLY TO THE ANTEROLATERAL REGION OF THE HUMERUS AND HUMERORADIAL JOINT

In a personal limited study of this region thirty elbows of adults were dissected. The investigation was concentrated on the nerve supply of the lateral epicondyle and the humeroradial joint. It was found that the periosteum and fibrous structures of the lateral distal end of the humerus are supplied mostly by branches of the radial nerve. These branches originate from the main trunk of the radial nerve after it traverses the lateral intermuscular septum at a point almost invariably ten or eleven centimeters proximal to the tip of the lateral epicondyle on

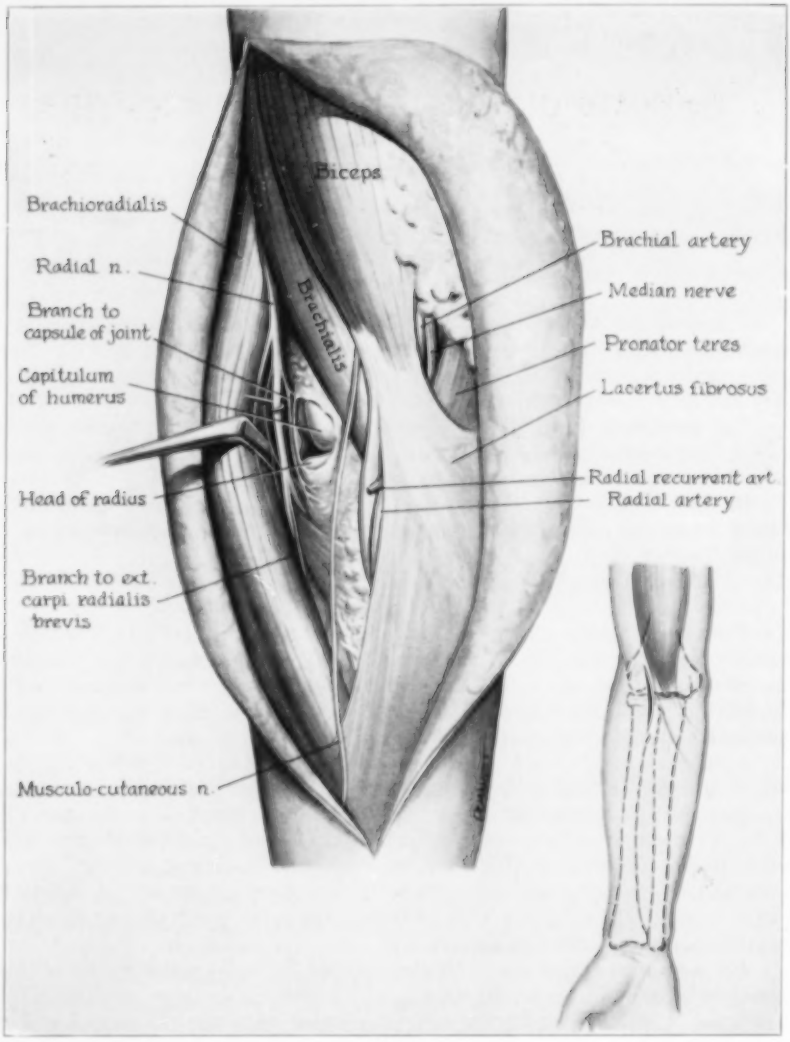

FIG. 1

the lateral epicondylar line of the humerus. After traversing the lateral septum, the radial nerve continues its course distalward first between the brachioradialis muscle on the outer side and the brachialis muscle on the medial side and then between the brachioradialis and the biceps brachii (Fig. 1).

About four to five centimeters distal to its emergence from the posterior compartment of the arm in the interval between the biceps and the brachioradialis, the radial trunk gives off a branch on its lateral side. This branch may remain single or divide into two or three filaments. It continues its course separately, but parallel to the main trunk, until it reaches the brachioradialis muscle on its deep surface where it is distributed to the substance of this muscle. This is the nerve to the brachioradialis. Another branch emerges from the main trunk, usually from the medial side, one or two centimeters distal to the nerve of the brachioradialis. This second branch can be traced to the periosteum of the lateral epicondyle, to the anterior structures of the humeroradial joint, and to the orbicular

ligament of the proximal end of the radius. A third branch, coming either from the common trunk or from the anterior division of the radial nerve on the lateral side, can be traced to the deep surface of the extensor carpi radialis longus muscle. This branch gives off twigs to the humeroradial joint.

The common trunk of the radial nerve in its passage from the intermuscular septum to the point of its terminal division into two branches, appears to be twisted on its long axis. There are fairly constant reference points suitable for the location of the main trunk of the nerve and its branches.

The division of the common trunk into two terminal branches takes place most frequently about four or five centimeters proximal to the humeroradial joint, less frequently about two centimeters distal to this point, and occasionally just in front of the joint. The anterior terminal sensory branch of the radial nerve is superficial, while the posterior motor branch is deep.

The radial nerve crosses from the posterior to the anterior compartment of the arm, in the average individual, at a point which is almost invariably ten centimeters to the tip of the lateral epicondyle.

With the elbow in full extension the humeroradial joint lies one centimeter distal to the bi-epicondylar line, or the line uniting the tips of the medial and lateral epicondyles. The radial nerve or its anterior branch crosses in front of the humeroradial joint at a point on the bi-epicondylar line two centimeters medial to the tip of the lateral epicondyle. The nerve supply to the lateral epicondylar region originates from the main trunk of the radial nerve as this nerve passes along the groove between the brachioradialis and the biceps muscle. All the nerves which furnish this supply are located between a point about four to five centimeters proximal to the bi-epicondylar line, and a second point three to four centimeters distal to this same line.

The musculocutaneous nerve represents an important guide to the location of the radial nerve. In the arm, the musculocutaneous is deeply situated between the brachialis and biceps brachii. It does not usually appear in the epicondylar region until it pierces the antebrachial fascia about two to four centimeters proximal to the bi-epicondylar line and medial to the cephalic vein. It then runs along the lateral border of the biceps tendon in close proximity to it. A longitudinal incision in the antebrachial fascia lateral to the musculocutaneous nerve leads to the groove between the biceps and the brachioradialis where the trunk of the radial nerve is found. The musculocutaneous nerve supplies the brachialis muscle; before piercing the fascia it sends an anterior branch to the periosteum of the anterior surface of the distal end of the humerus. This branch was described by Rüdinger. It anastomoses with a branch of the median nerve and runs to the most medial part of the distal end of the humerus. A similar anastomosis is occasionally found between a branch of the musculocutaneous and the radial articular branches supplying the lateral epicondylar region. No such anastomosis was found in the author's present dissections.

A branch from the long nerve to the anconeus muscle supplied the posterior aspect of the olecranon region. This branch was found to run for a short distance to the olecranon. It did not reach the posterior aspect of the lateral epicondyle.

APPLICATION

It appeared possible that interruption of the greatest part of the articular nerve supply to the lateral epicondyle would bring relief from pain in epicondylitis.

A. M., a white woman, forty-six years of age, had severe epicondylitis of the right elbow of about two years' duration. Conservative treatment consisting in injections into the epicondylar region, immobilization, and physiotherapy did not give relief. On March 9, 1957, operation was done at the Hospital for Joint Diseases with the patient under general anesthesia. Denervation of the epicondylar region was done as described. The patient was immediately

relieved of pain and has had no complaints in the region of the right epicondyle since the operation. She was discharged March 13, 1957. At the last examination on June 13, 1957, the patient was completely relieved of epicondylitis and the operation was considered to be successful.

W. A., a Negro man, fifty years of age, employed as a dining-car cook, had severe complaints of pain with weakness of grip and fingers and pain on extension of the thumb and index finger. He was treated several months with physical therapy and injections of procaine. No relief was obtained. On March 27, 1957, operation was done on the left elbow at the Hospital for Joint Diseases with the patient under general anaesthesia. Complete and immediate postoperative relief of pain was obtained. The patient was discharged on April 2, 1957. The patient has not had any pain since the operation and has returned to work. He was re-examined on July 31, 1957, and on July 8, 1958.

J. D., a white male, plumber for the New York Public Library, forty-four years of age, had marked epicondylitis of the right elbow. No relief was obtained from physical therapy. He was admitted to the Hospital for Joint Diseases on March 23, 1958. He was operated upon on March 24, 1958, under general anaesthesia. Denervation of the radial epicondyle and radiohumeral joint was performed. The patient was discharged April 1, 1958, and was last seen on June 7, 1958. A card subsequently received from the patient while on vacation, stated that he was absolutely without pain and had been able to return to his work.

As a preliminary test for the effectiveness of denervation, the periosteal and articular branches of the radial nerve are blocked by injecting a 1 per cent solution of procaine. If following the injection the patient has immediate relief of pain and is able to extend the thumb and wrist without discomfort, he is then considered a suitable candidate for the operation of denervation.

The technique employed for the nerve block is as follows:

The bi-epicondylar line is identified by palpation of the medial and lateral epicondyles. The needle is introduced at a point on this line one centimeter medial to the lateral epicondyle or just medial to the brachioradialis muscle. By directing the needle posteriorly it reaches the common trunk of the radial nerve at a point just proximal to the radiohumeral joint. The exact site for injection is determined by advancing the needle until it contacts the anterior surface of the humerus at a depth of 1.5 to two centimeters. It is then withdrawn slightly and the anaesthetic injected.

OPERATIVE TREATMENT

A curved incision, parallel to the medial contour of the brachioradialis muscle, is made on the anterior surface of the elbow. The incision is located between the brachioradialis and the biceps brachii (Fig. 1). It starts about six to eight centimeters proximal to the bi-epicondylar line and ends about four to five centimeters distal to the line. The antebrachial fascia is exposed and the cephalic vein identified. About two to four centimeters proximal to the bi-epicondylar line lateral to the tendon of the biceps brachii, the musculocutaneous nerve is recognized as it emerges through the fascia and runs distally parallel to the tendon of the biceps. The antebrachial fascia is incised parallel and lateral to the musculocutaneous nerve from one end to the other of the skin incision. Retraction of the fascia exposes the groove between the brachioradialis and the biceps muscle. This groove is filled with fat. Gentle blunt separation of the fatty tissue permits exposure of the trunk of the radial nerve and its branches. Exposure of the trunk of the nerve also uncovers the anterior recurrent radial artery which runs on the medial side of the radial nerve proximalward to join the radial collateral artery (branch of the deep brachial artery) deep to the nerve. The brachioradialis muscle is retracted laterally and the biceps tendon and muscle together with the musculocutaneous nerve are retracted medially. This opens to view, throughout the length of the incision, both the radial nerve and its branches. The articular branches can be identified and followed to their termination. Usually, the muscle branches emerge from the main trunk on the lateral side and the articular branches on the medial side in the supracondylar region. However, it is not difficult to follow the

branches to the epicondyle and the humeroradial joint and thus avoid destruction of the muscle branches.

The anterior sensory and the deep motor terminal branches of the radial nerve run closely together until the motor branch reaches a small opening in the supero-anterior border of the supinator muscle, just distal to the orbicular ligament of the radius. At this point not infrequently a branch is detached from the motor division of the radial nerve which runs to the deep surface of the extensor carpi radialis brevis and supplies this muscle.

After exposure of the trunk of the radial nerve, it is lifted gently and the articular branches are identified and excised completely from the anterior and lateral surface of the epicondyle. Bleeding from the small arteries covering this area is easily controlled.

After excision of these nerve branches, the muscles and nerves fall into their normal relationship. Only closure of the skin is necessary.

The operation is not difficult and only a short period of hospitalization is necessary. The relief from pain is immediate. To the present there have been no recurrences in the three patients treated by this method.

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Assay of Foreign-Body Reaction*

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Tissue reactions to foreign bodies range from the one extreme of chemical gangrene and violent inflammation to the other in which there is minimal observable change. It is doubtful whether any foreign body within the connective tissue truly causes no reaction whatsoever. Whenever one examines tissues which have contained foreign bodies for periods of longer than a few days, some degree of cellular reaction, however slight, is seen. The mechanism or mechanisms by which this reaction is mediated are not understood. Most of the materials which have been shown to elicit the minimal reactions have been metallic, plastic, or crystalline, and are very sparingly soluble in tissue fluids. Thus, where foreign bodies elicit only minor tissue reactions, it is not known whether mechanical stimulation of cells provides the principal stimulus to reaction or whether the chemical properties of the substance are also a factor.

Despite the increasing frequency with which many foreign materials are being implanted surgically, the resulting need for assay methods to compare their relative effects has not been met. Two major obstacles hamper this type of investigation. One is the difficulty of determining quantitatively the degree of tissue reaction, and the other is the difficulty in characterizing the stimulus. The present attempt to devise an assay of tissue reaction to a mildly or minimally provocative foreign body began with the hypothesis that increasing the surface area of the material exposed to tissue fluids would increase the tissue reaction to the material. The obvious method of comminution of a material presented an attractive means by which sparingly soluble materials could be made to present different areas of surface to tissue fluids, and it was hoped that materials considered inert in implantation experiments involving large implants could be shown to increase their reactivity when the surface of the implant was increased. The degree of success of the assay method is illustrated in this report and several methods are described, some of which were found only theoretically applicable at present, but of interest in the further development of more suitable procedures.

MATERIALS AND METHODS

The procedure developed consisted in pulverizing certain metals into fine particles, injecting them subcutaneously into rats, and examining the histological reactions at the injection sites at intervals.

Pulverizing of metals has become a separate specialized branch of technology because of numerous commercial applications. Recent texts [4,11] describe methods for production of particles and sampling procedures, all of which are pertinent to the subject but are too general for discussion here. The sources consulted in the development of the methods used included, in addition to texts and technical journals, consultations with various experts**. No specific methods now in use

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** Prof. John Wulff, Massachusetts Institute of Technology, gave general direction to the metallurgical aspects of the problem. Prof. Charles Richards, Massachusetts Institute of Technology, suggested the mechanical comminution by means of the vibratory mill, and Prof. Truman Licht, Boston College, supervised the inorganic chemical analyses. The journals of many disciplines contain the pertinent technical studies—for example, ceramics, metallurgy, engineering chemistry, and mineralogy—but no single one may be cited as representative of the field.

elsewhere were found fully applicable to the particular needs of this experiment. The method finally arrived at is here given in detail.

A rough sizing of powder samples was first done by sedimentation. Samples of powders obtained from commercial sources or obtained from industrial laboratories (Table I) were prepared for sedimentation by shaking them overnight either in saline or in distilled water with a drop of Tween 20, or in acetone. The suspensions were then placed in test tubes 1.5 centimeters in diameter and ten centimeters high and observed at intervals under incident light and under a dissecting microscope. Additional precautions to aid in minimizing conglomeration of particles consisted in boiling the suspensions before shaking or using other solutes, but substantially the same results were obtained in all instances. Complete sedimentation of the powders occurred in ten minutes to one hour by the following criteria: The supernatants were clear and contained no sedimenting particles under the conditions of observation; the precipitate was heavy and showed 94 to 102 per cent recovery by weight of the amounts of powder suspended. Microscopic examination of the suspension before sedimentation showed in the case of each powder, except Ta-2, a large preponderance of particles which ranged from ten to forty micra in diameter, measured by the mean linear intercept of Martin. Ta-2 showed particles mostly from five to twenty micra in diameter. Because of the relative sparsity of particles smaller than five micra in diameter, further determinations of size distribution were not made on these specimens.

Since finer powders than those listed were desired, pulverizing of cobalt chrome alloy, stainless steel, type 316, and low carbon mild steel was attempted by ball milling. A special vibrating mill was used embodying the principle of an eccentrically loaded axis activating a carriage on springs. Chambers and balls, one-quarter of an inch in diameter, of the desired metals were fabricated. To avoid contamination with other materials, each metal chamber with balls of the same metal and suspending fluid was milled separately, yielding particles which were abraded from the surfaces of the balls and the mill chamber. Continuous violent agitation of the chambers first yielded variable amounts of large particles which settled essentially as did the powders previously described. The yields of particles from the chambers were not great at first, but after a week of continuous operation, the steel chambers began to yield larger amounts of dark suspensions of particles, and after a month of continuous operation the cobalt chrome chamber also yielded suspensions of similar turbidity. For the next four months of operation, the chambers yielded suspensions of similar and rather constant turbidity in overnight runs. These suspensions did not settle appreciably on standing (the criteria have been previously described). When allowed to remain on the shelf in distilled water, none of the suspensions showed sedimentation in one to two weeks. The mild steel powder began to settle after four weeks of standing, while the type 316 steel powder settled only after four months and the cobalt chrome powder after six months. The supernatant liquid of these suspensions then appeared clear.

Sizing of the freshly milled metallic suspensions was attempted by centrifugation, after methods based on nephelometry and differential filtration had failed. The nephelometer was inefficient with these suspensions because of their high turbidity; cellulose filters clogged rapidly for the same reason. At 500 revolutions per minute ($25 \times G$) complete sedimentation of the three types of powder was obtained in ten minutes or less by the criteria previously enumerated. Calculated from the formulae of Svedberg, particles of a density eight grams per milliliter which sediment under the conditions of the centrifugation have a mean diameter greater than 0.06 micron. From Stokes' law, the calculated diameter for particles which settle on standing ten to sixty minutes in a beaker ten centimeters high, their density being eight grams per milliliter [9], equalled 0.4 to one micron. Thus sedimentation and centrifugation of individual runs from the mills were used to estimate the rough size distribution of the powder obtained in each

TABLE I

POWDERS USED *

Designation	Av. Part. Size (*Micra*)	Chemical Composition										Others				
		C	Co	Cr	Fe	Mn	Mo	Ni	Si	Ta	Ti	W	Amt.	Type	Source	Remarks
Ta_1	40 (−325 mesh)	max. 0.03			max. 0.03					99.7+		max. 0.05	max. 0.15	Cb	Fansteel Corp.	
Ta_2	2–30				max. 0.1				max. 0.05	99.2+	max. 0.01		max. 0.11	Cb, CaO, Na_2O	Shield Alloy Corp.	Si measured as SiO_2
Ti	5.7	0.008			0.017				0.03		Bal.		0.225	Mg, H, N	Titanium Corp.	
VS	−325 mesh	0.08		17.97	Bal.	0.88	2.35	11.12	2.31				0.026	S, P	Vanadium Alloy Steel Co.	
VC	−325 mesh	0	62.52	27.22	0	0.60	5.35	2.84	0.33				2.84	S, P	Vanadium Alloy Steel Co.	
SP	0.05–0.5	0.7			Bal.	0.9			0.5						Fabricated	Mill & balls from N. V. Tema Co.
MC	0.05–0.5	0.28	Bal.	27.4	0.56	0.5	6.26	2.98	0.42			0.36			Fabricated	Mill & balls from Austenal Corp.
MS	0.05–0.5	0.045		16.65	0.5	1.93	2.41	12.77	0.32				0.043	S, P, Cu	Fabricated	
Si	0.01–0.02								>99						Dow Corning Co.	Si present as SiO_2
Fe_2O_3	10	Technical Grade													Cole Mathiesson Co.	
FeO	10															

* Values given are those of suppliers. Some Co, Cr, and N determinations were checked colorimetrically and showed satisfactory agreement.

run. If the suspension did not settle on standing and sedimentation was brought about by centrifugation at 500 revolutions per minute in repeated determinations, the size distribution was taken to be between 0.5 and 0.05 micron, allowances being made for the experimental errors due to convection currents, Brownian movement, and inaccurate measurement of the speed of rotation of the centrifuge. The particle size distributions of a few mill runs were checked by measurements made on electron photomicrographs, and two examples of the distributions are tabulated in Table II. Measurements were made on the photomicrographs to

FIG. 1

Cobalt chrome alloy powder suspensions (× 26,800). The particles are granular or oblong. Some degree of agglomeration of particles is present because of preparation of specimen by evaporation of solute on grid.

the nearest millimeter, and it was from these measurements that a calculation of the surface area was made. Since the particles were oblong or square on the electron photomicrographs (Fig. 1) and since there was very little difference in the shape of the particles of cobalt chrome compared with particles of steel type 316, the size distributions of each of these powders could be calculated in the same way. The cobalt chrome particles were slightly smaller than the steel, but were comparable within the factors of error of measurement and sampling. For purposes of calculation of particle volume and surface area, the assumption was made that each particle rested on the grid with the long axis flat and that the thickness equaled the width. This introduced an error of overestimation for the thickness but eliminated the need for shape factors in the calculation. From the data given and the known density of the materials the surface area per milligram of each powder was calculated to be about 500 square centimeters. This

type of calculation was used to determine the surface area of metal exposed to the tissues by each injected sample.

Injectable samples were prepared by filling each chamber of the mill with boiled glass-distilled water after the mill chamber and balls had been thoroughly cleaned. Overnight runs of the mill yielded samples approximately 300 milliliters in volume containing from 0.3 to 0.5 gram of powder. Each injection sample contained 0.25 milligram of the powder. The slurry was removed from the chamber and allowed to stand for one hour to determine whether settling had occurred. If not, aliquots were then removed for weighing, centrifugation, culture, and preparation of injections. By calculations from the dry weight of aliquots, the volumes of the injections could be so chosen to deliver equal weights of powder to each animal. Generally the volumes used were 0.2 to 0.4 milliliter. Bacterial cultures of the slurries uniformly showed no growth so that sterilization was not

TABLE II

DISTRIBUTION OF PARTICLE SIZES IN MILLED POWDERS

Volume in μ^3	Steel Type 316 (*No. of Particles*)	Cobalt Chrome (*No. of Particles*)	Volume in μ^3	Steel Type 316 (*No. of Particles*)	Cobalt Chrome (*No. of Particles*)
5×10^{-5}	923	801	9×10^{-4}	0	18
1×10^{-4}	342	344	1×10^{-3}	12	17
1.5×10^{-4}	123	161	2×10^{-3}	79	129
2×10^{-4}	88	108	3×10^{-3}	29	51
2.5×10^{-4}	66	53	4×10^{-3}	12	31
3×10^{-4}	49	64	5×10^{-3}	7	14
3.5×10^{-4}	49	46	6×10^{-3}	2	7
4×10^{-4}	63	39	7×10^{-3}	0	0
4.5×10^{-4}	19	18	8×10^{-3}	6	7
5×10^{-4}	15	15	9×10^{-3}	0	0
6×10^{-4}	46	33	1×10^{-2}	0	1
7×10^{-4}	4	5	2×10^{-2}	1	1
8×10^{-4}					

deemed necessary. Sterile disposable syringes with rubber-lined plungers were used for the injections because the powder caused glass syringes to bind and they were impossible to clean thoroughly once used. Each animal received, in the left flank, a subcutaneous injection of a suspension of steel and in the right flank a similar injection of cobalt chrome alloy. When other powders were being tested, a similar routine was used so that each animal provided two test specimens when sacrificed. During the first stages of the experiment adult rats as well as weanling rats were used, but as the experiment progressed and little difference was noted in histological preparations from weanling as against young adult and older animals, the experimental animals chosen were weanlings. Each animal was kept in a separate wire suspended cage under standard laboratory conditions. Over 500 rats were used, and each sacrifice period, with the exception of the year-long experiment, included at least ten rats. The year-long experiments were completed on only seven rats. In addition to the above animals, twenty-eight young adult hamsters were also used in the experiment. There were no essential differences in tissue reactions from those in the weanling rats.

RESULTS

The tissue reaction to the *coarse* powders listed in Table I were studied for the following intervals: two days, four days, one week, two weeks, and one month. No differences were noted in the type of degree of reaction elicited. At two days, grossly the skin showed slight hyperaemia but very little thickening. The grey powder was very easily found at the site of injection. When the skin

was peeled from the muscle and fascia by blunt dissection, the powder was found adhered to the skin from which it could be scraped only by sharp dissection. The gross appearance of the tissue was little changed from the normal except for the grey residue in it. Occasionally injections were at a deeper level than the subcutaneous, and deposits of powder could be found in the abdominal muscle or in the breast tissue. Here, too, the powder lay spread out in tissue planes with little oedema and no gross inflammation. The powder seemed to spread over larger areas subcutaneously, however, and their extent averaged two by three centimeters in the subcutis and only one by one centimeter in the muscle layer. Specimens from animals sacrificed at longer intervals than two days did not show any appreciable difference in gross reaction to that described above.

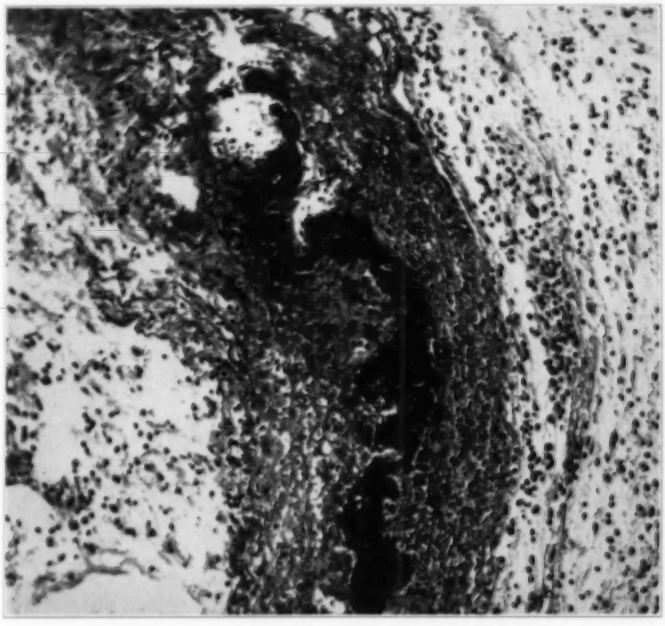

FIG. 2

Four-day reaction to cobalt chrome powder (× 170). Cellular reaction is mainly polymorphonuclear. Powder is entirely extracellular.

Microscopically the degree of inflammation around the particles was very mild. A few mononuclear and neutrophilic leukocytes were evident at two and four days following injection and by one week the neutrophiles were no longer to be seen, and only a few fibroblasts and mononuclear cells were present. Minimal phagocytosis of particles was evident in many of the sections, including those made of specimens representing tissue reactions of one month's duration. The reaction at that time consisted of minimal fibrous tissue adjoining the particles and a few mononuclear cells and lymphocytes.

The tissue response to *fine* powder of *cobalt chrome* differed significantly from that to coarse powder microscopically; grossly the reaction was not very different. Even after one year in the tissues, the grey powders could easily be found, although surrounded by a slight and progressively greater thickening of the tissue. This thickening was appreciable by the second day after injection and was most apparent after one month. In the specimens studied representing two, three, four, six, and twelve months after injection, little difference could be seen grossly in the thickening of tissues containing the cobalt chrome powder.

Microscopically, even the two-day specimens revealed significant reactions. Moderate numbers of polymorphonuclear leukocytes infiltrated the tissue near the powder and for two or three low-power fields around it. A few mononuclear cells were also present, none of which showed phagocytosis of powder particles. Oedema was only moderate. After four days (Fig. 2), the number of polymorphonuclear leukocytes decreased somewhat; and, after one week, no significant number was found. The mononuclear cells were somewhat more numerous and after

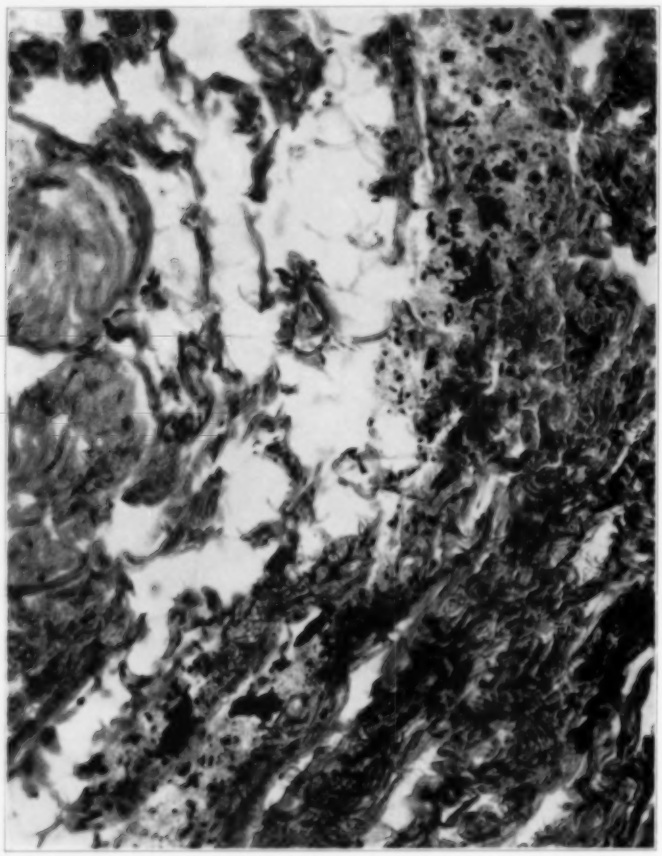

FIG. 3

Two-week reaction to cobalt chrome powder (× 240). Fibrosis is minimal. Powder remains primarily extracellular. A few phagocytes contain granules.

two weeks (Fig. 3) a few of them showed phagocytosis of metallic granules. The largest part of the injected metal remained in layers extracellularly and surrounded by a small amount of fibrous tissue. In specimens from animals sacrificed four months (Fig. 4), six months, and one year (Fig. 5) after injection, the number of mononuclear cells was small and many contained phagocytosed metallic particles so that the amount of powder extracellularly located was moderately diminished from that in earlier specimens. The largest portion of the injected powder apparently remained in an extracellular mass. The degree of fibrosis around the cobalt chrome powder was progressively greater with time until about three months after injection, but thereafter no significant increase

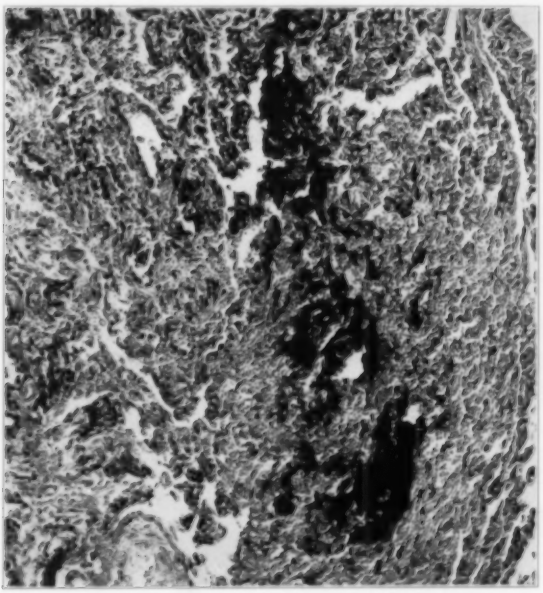

FIG. 4

Four-month reaction to cobalt chrome powder (× 170). Reaction continues to be one of slight fibrosis and most of the powder is extracellular.

in fibrosis was noted. In the later specimens, the mononuclear cells were fewer, and most of them contained metallic granules.

The tissue response to the *fine* powder of *steel type 316* was greater in degree than the tissue reactions to coarse powder particles or to fine cobalt chrome powder. Grossly this was not evident in the two or four days after injection when compared with the reactions from cobalt powder on the contralateral side of the same animal. The specimens obtained one week after injection definitely showed greater thickening of the connective tissues and increased oedema. Thickening was not of palpable degree; it was only evident after the animal was skinned and the grey steel powder was located. The thickening was then found to be diffuse and often extended to the neighboring muscle layer to which some adhesion at the site was evident. The specimens obtained four, eight, and twelve weeks after injection showed progressively denser thickening of the area. In the six-month specimens, however, the reaction was identified with difficulty because the exact location of the powder was hard to find in the animals which now had a thick panniculus. The reactions in the one-year-old specimens were even harder to identify compared with the continued localized collection of cobalt chrome powder on the opposite side. For this reason, where the grey powder could not be identified with certainty either by inspection or by transillumination of the skin, sample sections gridding the area were taken. By this technique, residual powder always could be recognized microscopically.

Histologically, the specimens obtained four days after injection (Fig. 6) revealed larger accumulations of leukocytes around the powder than in the cobalt chrome specimens. The area of reaction was also somewhat larger and more oedematous. At two weeks, however, the differences were striking (Fig. 7). Large numbers of mononuclear cells were present, many containing finely divided metal granules which stained with Prussian blue. Leukocytic accumulations persisted even to the second week while the mononuclear cells became more numerous and

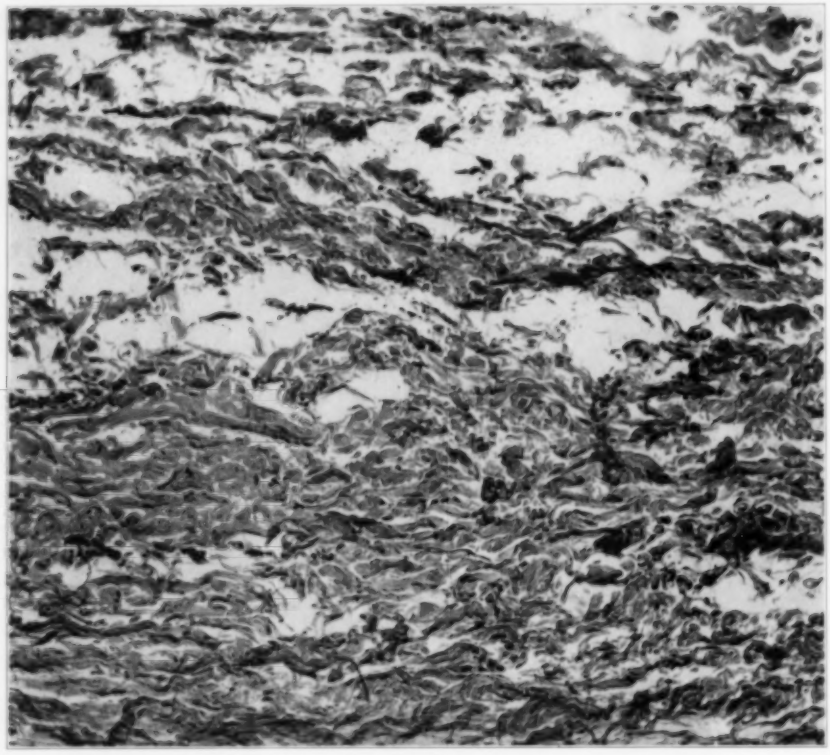

FIG. 5

One-year reaction to cobalt chrome powder (× 170). Reaction of the muscle to the powder ranges from slight to negligible. A few phagocytes are scattered among the muscle fibers. Fibrosis is minimal.

often encapsulated the extracellular masses of powder. Specimens (Fig. 8) obtained one month after injection showed significant fibrosis, continuing mononuclear accumulation, and phagocytosis of particles and apparent decrease in the amount of powder remaining extracellularly. Specimens obtained two and three months after injection revealed progressively fewer mononuclear cells, but extensive fibrosis, and in the specimens obtained six months and one year after injection, only a little powder could be found, principally in the intracellular location, dispersed within a rather large fibrous mass (Figs. 9 and 10).

Until the six-month specimens were obtained, interest was centered exclusively in a localized reaction of the subcutaneous tissue and muscle containing the powders. When dissemination of the powders was evident, sections were taken routinely of the lung and occasionally of the breast. The six-month and one-year specimens revealed iron granules in the macrophages of the lung. While the pulmonary distribution is in accord with that described for other so-called inert particulate materials injected, for example, vital dyes and India ink, uninjected old rats often showed iron deposits in the lungs similar to those demonstrated in these animals.

Tissue reactions to *fine* powders of *mild steel* were grossly inflammatory in all the specimens examined. In the one-week specimens, it was uniformly seen as purulent accumulations which measured one to two centimeters in diameter. The one-month specimens contained purulent material thickly encapsulated with

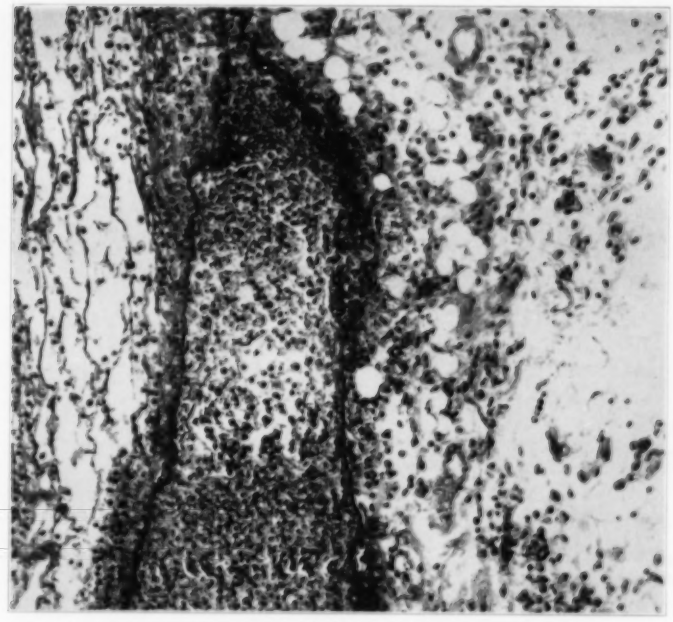

FIG. 6

Four-day reaction after injection of the fine powder of steel type 316 (× 200). Powder is noted as layers, mostly extracellular. Cellular reaction is primarily polymorphonuclear and mononuclear.

fibrous tissue. Similar gross appearances were seen in the specimens obtained from injection sites of silica (partical size ten to twenty millimicra)*.

Microscopically, the effects of the low-carbon mild-steel, fine powder and fine silica powder were those of acute inflammation which persisted actively over the entire one-month observation period. Micro-abscesses were numerous and continuing inflammation of acute type, with outpouring of fibrin, oedema, and leukocytes was evident throughout, while fibrosis was extensive by the end of the one-month period of observation.

Summarizing the microscopic observations, the reactions may be divided into four categories. The *minimal* reaction was elicited by all of the coarse powders used. A *mild* reaction was elicited by cobalt chrome alloy powder of fine particle size. A *moderate* reaction was elicited by stainless-steel powder of fine particle size. The *severe* reaction was elicited by fine powders of mild steel and silica.

DISCUSSION

The investigation of tissue reactions to implanted metals has a long history, based principally on studies of histological reactions to large implants. From these studies, observers have concluded that only a few metals and plastics are inert as far as eliciting inflammation is concerned. The present experiments have shown that inertness is relative and that, in the form of fine powders, even those materials considered least provocative of inflammation, will cause appreciable tissue reaction. A single substance (for example, type 316 steel) may elicit only minor inflammatory change when exposed to tissues as coarse powder, while

* Prepared for injection in samples containing comparable surface areas to those used for other powders. The particle-size determinations are those of the supplying company, and the assumption was made that the particles were spherical.

FIG. 7

Two-week reaction to the fine powder of steel type 316 (× 170). The reaction is now nodular with fibrosis at the periphery. There are intracellular as well as extracellular iron-containing granules and many mononuclear cells.

with finer comminution significant changes are noted. Similarly, reactions to powders of different metals may be indistinguishable at one degree of comminution while a finer particle size will easily differentiate them.

While it is undoubtedly true that comminution may alter the surface characteristics of a material, the most apparent alteration is that of surface area. As calculated for each injected sample of the fine powders, the surface area was far greater than that of the solid implants used in previous studies. The tissue exposure in the present experiments was concentrated within a much smaller volume. These factors may have led to summation or potentiation of the inflammatory reaction. Under the conditions of the experiment and, indeed, wherever metals have been implanted, the surface exposed to the tissue probably consisted of metallic oxides or hydroxides, but during the period of the experiment, changes in the particles probably occurred. The sudden sedimentation *in vitro* of particles after months of standing in turbid suspension indicates some change, probably oxidation and formation of hydroxides, and it may be assumed that similar alterations occurred in the tissues.

The solubility in water or in dilute electrolyte solutions of each of the metals or their hydroxides or oxides at the pH range ordinarily present in tissue does not exceed five parts per million. Hence it is probable, for shorter experimental intervals at least, that no large fraction of the injected powders was dissolved. It is also probable that, after the first few days of acute reaction, subsequent chronic reaction to the powders was based on interaction of hydroxides and tissue fluid at the particle surface.

Only a few investigators in the field of experimental pathology have pro-

FIG. 8

One-month reaction to the fine powder of steel type 316 (× 170). Less extracellular powder is now seen with more phagocytosis of granules and more monocytic reaction.

vided material pertinent to discussion of these studies. With reference to metallic particles, Bailey and his associates described implantation in the central nervous system of tantalum in the form of particles 10 to 50 micra in diameter; the reactions were analogous to those seen for most of the coarse powders in this study. McCord and his associates demonstrated chemical gangrene with gas formation from the subcutaneous implantation of small particles of magnesium (size not determined) while large spicules merely caused moderate inflammation. They reviewed the literature on other light metals such as aluminum and showed that when implanted as powders they too evoke an inflammatory response more marked than seen in the present study. Schultz and Williams were the only investigators working on talc granuloma who considered particle-size distribution as well as the variable composition of talc as an important factor in the production of inflammation.

The major field of experimental pathology in which investigators evaluated tissue reactions to sparingly soluble materials in particulate form is that concerned with silica. These studies have usually been concerned with pulmonary reaction although Swensson and his associates described toxicity to intravenous injection of particles of silica into mice, the smaller particles being more toxic than the larger ones. The remarkably divergent conditions in pulmonary and subcutaneous tissues as test sites for reaction are illustrated by the different types of cells exposed, the different factors influencing dispersion and different mechanisms of disposal of irritants. Nevertheless the data derived from studies of silica toxicity are informative and probably parallel inasmuch as they are concerned with the surface of small particles and its influence on the type of tissue reaction. Interest in particle sizes in these studies stems in part from the industrial dust

FIG. 9

Six-month reaction to the fine powder of steel type 316 (× 170). Here the reactive tissue is mainly fibrous with many granule-laden macrophages interspersed between the fibers.

problem, and it is interesting that there is so little information on the toxicity of dusts. With the increasing applications of powder metallurgy, further experimentation in this field seems indicated.

Hounam investigated the colloidal properties in inert dusts *in vitro* and pointed out that the charge on the hydrophobic sol particle influenced the stability of the suspension. He suggested that toxicity of dusts is related to the stability of suspensions which in turn depends on the degree of charge. In his experiments, ferric oxide formed a stable suspension although without charge and he ascribes this unusual situation to hydration of the particles. The applicability of these suggestions to metallic dusts implanted as aqueous suspensions rather than inhaled rests on the similar particle size distribution of the silica to that of the metal powders used, the polyvalent character of the principal components (Si, Fe, Cr, and Co) and the similar low solubility in water and dilute electrolytes of the materials used. The marked differences in reaction between tissue exposed to silica dust and to the fine powders of cobalt chrome alloy and stainless steel

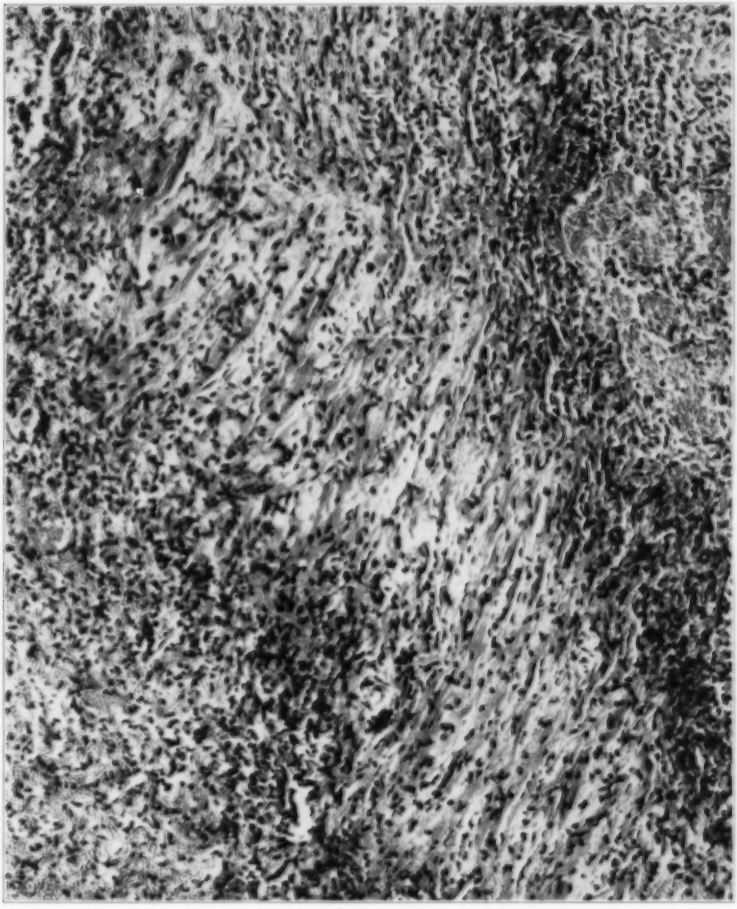

FIG. 10

One-year reaction to the fine powder of steel type 316 (× 170). Large amounts of powder are still seen extracellularly as well as intracellularly. Marked fibrosis continues.

type 316 are evidence that Hounam's suggestions while pertinent to the stability of suspensions do not explain the differences in tissue reactivity.

Setting aside the reactions of the individual compounds of the surface layers with those of the tissues as too speculative for discussion, the most attractive explanation for variation in degree of reaction is that there may be variation in the number of metallic hydroxide molecules available to the tissue fluids for reaction. While this number, in initial exposure of the materials to tissue, is larger with increasing comminution of particles, the possibility of further increase during the course of the experimental exposure resembles in essence one of the principal problems encountered in the phenomenon of metallic corrosion.

The literature in this field is extensive and generally is not of interest to those occupied with biological studies. LaQue states that the degree of protection which the surface film on a metal provides for the metal against the corrodent will be the critical factor in the rate of corrosion. Since different elements in any environment react to varying degrees with each of the constituents of alloys,

or even to minute impurities in the metal, materials may not be validly classified according to absolute scales of corrosion resistance except in relation to standard testing conditions in the environment. Now, tissue fluid is so complex and capable of so much variation that it is doubtful whether any material may be compared with another with regard to its corrodibility in tissue except on an empirical basis. It should be pointed out, however, that the corrosion rate of many materials tested in dilute electrolytes or in sea water approximates in general, their comparative ability to elicit tissue reaction as judged by assay methods based on implantation of large test specimens. Thus tantalum, cobalt chrome alloy, stainless steel type 316 [5], and titanium [2] all have been considered non-provocative of significant tissue reaction. In water, none of these materials show significant weight loss. This is also true in dilute saline [3]. In LaQue's galvanic series based on potentials in sea water, all show low values; some show a significantly wide range of values, especially in the stainless-steel series. It is to be hoped that more refined methods of corrosion testing will reveal the essential factors in the composition of these materials which relate to their corrodibility in tissue fluids. In-service tests, however, will still constitute the ultimate measure of the degree of reaction of tissues to metallic substances.

The experiments reported here have illustrated a method which may be applied to most metals for assay of their ability to provoke tissue reaction. Further refinements along the lines indicated may be of practical value for development of a better method of assay and to elucidate the mechanism of tissue reaction to foreign bodies.

CONCLUSIONS

1. A method is described for comparison of metallic substances with reference to their capacity to evoke inflammation when used subcutaneously.

2. Powders of the test metal may be compared with similar powders of other metals by injecting suspensions of them into animals and examining the histological reaction at intervals.

3. By this method, very fine powders of several substances including type 316 stainless steel, and a cobalt chromium alloy were compared. All showed some degree of reaction, the least being evoked by the cobalt chrome alloy.

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The Practical Importance of Synovial-Fluid Analysis*

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A group of three relatively simple laboratory procedures performed on synovial fluid has been of great assistance to us in establishing earlier and more accurate diagnoses in the various forms of joint disease. These tests are a total and differential leukocyte count, an evaluation of the quality of the mucin content by a method of acetic-acid precipitation, and the determination of the difference between the concentrations of the serum and synovial-fluid sugars. They have been described in a monograph by Ropes and Bauer which also reports other data derived from analyses of synovial fluid from more than 1,500 patients and normal subjects. The results of synovial-fluid examination on 119 patients (Tables I, II, and III) with various forms of arthritis studied at University Hospitals in Cleveland have been similar to those reported by Ropes and Bauer and have led to the conclusion that these tests are of significant value in differential diagnosis. These tests were performed mainly for assistance in diagnostic problems arising in the Arthritis Clinic and wards of University Hospitals. It will be shown that in many instances synovial-fluid analysis can provide an important clue or actually establish a correct diagnosis early in the course of the disease. It should be emphasized that, as with other laboratory procedures, synovial-fluid analysis cannot supplant a thorough history and physical examination, although it can provide invaluable additional information.

PROCEDURES

Synovial fluid is aspirated by the usual technique while the patient is fasting, preferably for twelve hours. The fasting state is necessary for significant determinations of differences between the serum and synovial-fluid sugar concentrations. This difference is influenced by a normal lag of glucose transport across the synovial membrane. At least three milliliters of synovial fluid are necessary for the performance of the three tests. One milliliter is mixed with powdered oxalate to be used for the cell count and for smears. Both leukocytes and erythrocytes are enumerated in a counting chamber after the synovial fluid has been diluted in saline in a white cell pipette in place of the usual white cell dilutent which contains acetic acid. The differential count is made on a thin cover-glass smear stained with Wright's stain. As will be shown later, the total leukocyte count does not normally exceed 200 cells per cubic millimeter and the total erthrocyte count, 2,000 cells per cubic millimeter.

Sugar determinations and mucin precipitation tests are performed on a non-oxalated aliquot. Serum and synovial-fluid sugar can be determined by the macromethod of Folin or by various modifications of the Somogyi micromethod. The difference between normal synovial-fluid and serum sugars does not exceed 20 milligrams per 100 cubic centimeters in the fasting state.

In the mucin-precipitation procedure, 0.1 milliliter of 7-normal acetic acid

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is added to 1.0 milliliter of synovial fluid diluted with 4.0 milliliters of distilled water. Normal synovial fluid produces a characteristic precipitate which appears as a tight ropey clump in a clear solution. In diseases with severe inflammatory reactions of the synovial membrane, degradation of hyaluronate presumably occurs and the character of the acetic-acid precipitate is loose and stringlike with cloudiness of the surrounding solution. Four grades of mucin precipitation are recognizable—namely, normal, fair, poor, and very poor (Fig. 1).

A third portion of synovial fluid should be collected in a sterile tube for culture purposes if the leukocyte count or other studies suggest infectious arthritis. Further smears with bacterial stains can be made from the oxalated aliquot when indicated.

RESULTS

On the basis of these tests, Ropes and Bauer have grouped the majority of arthritides into two categories based on the degree of inflammation of the synovial membrane as reflected by the synovial-fluid changes. The first group, consisting of degenerative arthritis, neuropathic arthropathy, and post-traumatic arthritis, is associated with mild inflammatory reactions and an increased amount

TABLE I

119 Cases of Synovial-Fluid Analysis

Degenerative arthritis		19
Traumatic arthritis		3
Neuropathic arthropathy		1
Lupus erythematosus		2
Rheumatic fever		3
Pigmented villonodular synovitis		3
Rheumatoid arthritis		41
Gout		3
Tuberculous arthritis		2
Pyogenic arthritis		16
	Total	93
Diagnosis not established		13
Non-specific bursitis		5
Chondromalacia patellae		3
Periarteritis nodosa		2
Reiter's syndrome		1
Intermittent hydrarthrosis		1
Sickle-cell anaemia		1
	Total	26

of fluid, but no significant change in the number of leukocytes, sugar concentration, or the quality of the mucin. The second group is characterized by more severe inflammation of the synovial membrane and includes rheumatoid arthritis, gout, tuberculous, and pyogenic arthritides. An intermediate group of unrelated conditions—systemic lupus erythematosus, pigmented villonodular synovitis, and acute rheumatic fever—may have some distinguishing characteristics of the synovial fluid, although these are not usually diagnostic.

The results of the application of these tests in a group of 119 patients with diagnostic problems (Tables I, II, and III) compare favorably with identical studies performed by Ropes and Bauer. Twenty-three patients in Group I had consistent findings with an average leukocyte count in those with degenerative arthritis of 500 cells per cubic millimeter and with the differential count showing a marked predominance of lymphocytes. The average serum-synovial fluid sugar difference in patients with degenerative arthritis was 9 milligrams per

100 cubic centimeters. The synovial fluids from forty-one patients with rheumatoid arthritis had an average leukocyte count of 10,400 with 55 per cent polymorphonuclear neutrophils. Ropes and Bauer reported 152 patients with rheumatoid arthritis with average leukocyte counts of 15,000 and 65 per cent polymorphonuclear neutrophils. Our average sugar difference in these patients was 22.5 milligrams per 100 cubic centimeters. The considerable variation in leukocyte counts noted in the patients with rheumatoid arthritis (Table III) is caused by the varying degrees of inflammation characteristically encountered in this disease. This must be considered when interpreting these tests as overlapping with infectious arthritis can be expected. Further means of differentiation will be elucidated. Our experience with tuberculous arthritis is not sufficient to draw conclusions, but Ropes and Bauer reported twenty-seven patients with average leukocyte counts of 19,500 and 60 per cent polymorphonuclear neutrophils. An arbitrary figure of leukocyte response for differential diagnosis of rheumatoid arthritis and tuberculous arthritis is not feasible. A significant observation has

TABLE II

GROUP I RESULTS

Degenerative Arthritis		19 cases
Mucin precipitate	Normal	11
	Fair	8
Leukocyte count	High	1900
	Average	500
	Low	50
Polymorphonuclear neutrophils	Average	13%
Sugar difference	High	19 mgs.
	Average	9 mgs.
	Low	0 mg.
Traumatic Arthritis		3 cases
Mucin precipitate	Normal	3
Leukocyte count	High	1500
	Average	1200
	Low	800
Polymorphonuclear neutrophils	Average	5%
Sugar difference	High	12 mgs.
	Average	6 mgs.
	Low	3 mgs.
Neuropathic Arthropathy		1 case
Mucin precipitate	Normal	
Leukocyte count		300
Polymorphonuclear neutrophils		38%
Sugar difference		15 mgs.

been made, however, that in early cases of tuberculous joint involvement there is a predominance of lymphocytes with a high total leukocyte count [9]. Little difficulty was encountered in detecting the pyogenic joint infections as the leukocyte counts averaged 62,000 with 85 per cent polymorphonuclear neutrophils in sixteen patients. The serum and synovial-fluid sugar difference in these was the greatest in the whole series, averaging 50 milligrams per 100 cubic centimeters. A consistent reciprocal relationship between the total leukocyte count and sugar difference in Group II patients was encountered throughout this study.

The determination of the sugar difference is of greatest importance in the differential diagnosis of infectious arthritis. The presence of infection in a joint has long been known to be characterized by a decrease in concentration of synovial-fluid sugar, perhaps due to the large number of leukocytes present or an increase in metabolism of the inflamed synovial membrane [1,3,5,7,9]. A sugar difference of 20 milligrams per 100 cubic centimeters has been found by Ropes and

Bauer to be the upper limit of normal and is characteristic of Group I patients. A greater sugar difference has been observed in rheumatoid arthritis of more than six months' duration, but has not been of the magnitude seen with infectious arthritis. The degree of inflammatory activity in rheumatoid arthritis is reflected in the sugar difference as well as in the leukocyte count. It is pertinent to the conclusions of a reciprocal relationship between cell count and sugar difference that patients with rheumatoid arthritis, following treatment with cortisone, will have a significant reversal of these patterns. Moreover, the quality of the mucin precipitate also may show improvement during steroid therapy [2,6,8].

TABLE III

GROUP II RESULTS

Rheumatoid Arthritis		41 cases
Mucin precipitate	Normal	1
	Fair	9
	Poor	19
	Very Poor	12
Leukocyte count	High	38,650
	Average	10,400
	Low	150
Polymorphonuclear neutrophils	Average	55%
Sugar difference	High	55 mgs.
	Average	22.5 mgs.
	Low	0 mg.
Gout		3 cases
Mucin precipitate	Normal	1
	Fair	2
Leukocyte count	High	6,250
	Average	5,400
	Low	2,650
Polymorphonuclear neutrophils	Average	44%
Sugar difference	High	14 mgs.
	Average	12 mgs.
	Low	10 mgs.
Tuberculous Arthritis		2 cases
Mucin precipitate	Fair	2
Leukocyte count	High	58,300
	Low	42,200
Polymorphonuclear neutrophils	Average	88%
Sugar difference	High	40 mgs.
	Low	32 mgs.
Pyogenic Arthritis		16 cases
Mucin precipitate	Normal	1
	Fair	3
	Poor	4
	Very Poor	8
Leukocyte count	High	366,000
	Average	62,000
	Low	12,200
Polymorphonuclear neutrophils	Average	85%
Sugar difference	High	150 mgs.
	Average	50 mgs.
	Low	15 mgs.

The quality of the acetic-acid mucin precipitate is of greatest value in differentiating Group II cases from those of Group I. Traumatic and degenerative arthritides are most frequently associated with a normal mucin precipitate while, in our experience, rheumatoid arthritis has very rarely been associated with a normal precipitate. In the latter disease, the mucin is usually found to be poor or very poor. Similar degradation of the hyaluronate occurs in the infectious

arthritides and in most instances a poor or very poor precipitation is observed. Some diagnostic difficulty was encountered in the ten patients with rheumatoid arthritis with fair or normal mucin precipitation (Table III). The lowest leukocyte count in this group was 6,000 and in all there was a predominance of polymorphonuclear neutrophils. As stated initially, the biggest asset of this test is the high degree of accuracy in ruling out degenerative or traumatic conditions in patients with poor or very poor mucin precipitation tests.

The results of these tests in patients with gout resemble the response in those with rheumatoid arthritis, but synovial-fluid analysis is rarely of value in that diagnosis in gout depends on an elevated serum uric acid.

Pigmented villonodular synovitis is not associated with characteristic changes in regard to these three tests, but inspection of the aspirated fluid shows evi-

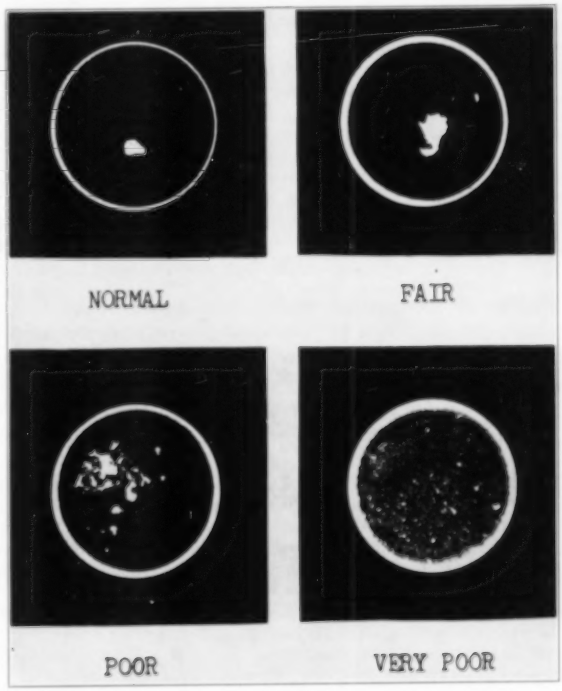

FIG. 1

The four grades of mucin precipitation photographed in glass beakers on a black background. (Reproduced with the permission of the authors and publishers: Ropes, M. W., and Bauer, Walter: Synovial Fluid Changes in Joint Disease. The Commonwealth Fund, Harvard University Press, 1953.)

dence of significant joint hemorrhage, and on spinning down the erythrocytes, xanthochromia can frequently be demonstrated [4].

The joint manifestations of systemic lupus erythematosus are occasionally indistinguishable from rheumatoid arthritis, but in striking contrast, the mucin precipitate has practically always been found normal (Ropes and Bauer, thirteen cases; present series, two cases). This may be apparent at the time of aspiration when difficulty withdrawing the viscous fluid is observed. This is in marked contrast to the less viscous fluid in rheumatoid arthritis. The inflammatory reaction in systemic lupus erythematosus, as judged by the leukocyte count and the sugar difference, is mild.

The joint manifestations of rheumatic fever are usually evanescent and the

results of the synovial-fluid are not distinctive. It is interesting that a moderate leukocyte response occurs with a normal mucin precipitate and this may occasionally be of help in the differential diagnosis.

CASE HISTORIES

CASE 1. R. H., an unemployed laborer, fifty-eight years old, had trouble with his left knee for several years prior to an operation performed in 1941 at another hospital. The pathological report was acute and chronic villous synovitis and degeneration of both menisci. A synovectomy and bilateral meniscectomies were carried out. Similar difficulty subsequently occurred in the right knee; and, in 1953, at a second hospital, a patellectomy and synovectomy of the right knee were performed. The pathological diagnoses were villous synovitis and chondromalacia of the patella. The patient was seen in the Arthritis Clinic in 1956 with continued severe bilateral knee pain and swelling. He also had minor complaints regarding both ankles, wrists, and elbows.

Examination of the left knee revealed moderate swelling and increased heat, as well as marked lateral and posterior instability. The right knee was not swollen or warm, but demonstrated only 80 degrees of flexion with pain. There was thickening and tenderness about both ankle joints but no limitation of motion. Diffuse rather mild psoriasis of the skin was noted. Roentgenograms of both knees showed marked degenerative joint changes and absence of the patella on the right. The corrected sedimentation rate (Rourke-Ernstene method) was 0.8 millimeter per minute (normal 0.4 millimeter per minute) and the serum uric acid was 5.8 milligrams per 100 cubic centimeters.

Synovial-fluid analysis was carried out with the following results: white blood count, 300 cells per cubic millimeter of which 60 per cent were lymphocytes and 40 per cent were monocytes; red blood count, 1,850 cells; serum sugar, 67 milligrams per 100 cubic centimeters; and synovial-fluid sugar, 65 milligrams per 100 cubic centimeters; mucin precipitation was normal.

The possibility of rheumatoid arthritis in addition to the degenerative changes in the knee demonstrated by roentgenogram was quite conclusively ruled out by the synovial-fluid findings. There were several points in this man's history, physical findings, and laboratory examinations which strongly suggested rheumatoid arthritis. Subsequent follow-up of this patient, in whom degenerative arthritis was treated conservatively, proved our initial diagnosis.

CASE 2. M. G., a widow, sixty-seven years old, was admitted to University Hospitals in July 1956 because of inability to walk of four days' duration. The right knee had been causing trouble for five months, and there was a history of trauma to this joint twenty years previously. She also gave a history of "mild arthritic complaints for many years". Examination revealed swelling and increased heat in both knees with pain on manipulating the right one. Some swelling was also noted in the left wrist and metacarpophalangeal joints. Rather severe Heberden's node changes were present in both hands. Roentgenograms revealed degenerative arthritic changes in both shoulders, both hands, and both knees with more marked narrowing of the right joint space. The corrected sedimentation rate (Rourke-Ernstene method) was 1.2 millimeters per minute.

Synovial-fluid analysis carried out at that time showed the following: white blood count, 22,650 cells per cubic millimeter of which 86 per cent were polymorphonuclear neutrophils, 6 per cent lymphocytes, and 8 per cent monocytes; serum sugar, 102 milligrams per 100 cubic centimeters and synovial-fluid sugar 96 milligrams per 100 cubic centimeters; mucin precipitation was poor.

These findings helped to confirm the diagnosis of rheumatoid arthritis which was somewhat clouded by the minimal preceding symptoms and diffuse degenerative arthritic changes seen on roentgenographic examination. The high leukocyte count, high percentage of polymorphonuclear neutrophils, and poor mucin precipitate left little doubt that her complaints were due to a severe inflammatory process and not to the degenerative changes. On a recent follow-up examination, this patient demonstrated further typical rheumatoid arthritic changes.

CASE 3. R. D., a fourteen-year-old Negro boy was admitted to University Hospitals in January 1958 with complaints of bilateral swollen painful knees of three weeks' duration. There was no preceding infection or trauma, but he had had mild intermittent pain in the right hip for eighteen months. Two weeks before admission, his family doctor aspirated the left knee and injected hydrocortisone. This knee subsequently became more swollen and

painful than the right. Examination revealed the joint changes were limited to both knees which were markedly swollen. The left knee demonstrated greater warmth and tenderness. Both joints were painful on manipulation. Temperature on admission was 101.3, and the changes in the knee were the only apparent causative factor. Roentgenograms of both hips and knees were normal.

On admission, January 28, 1958, synovial-fluid analysis was carried out on specimens from both knee joints.

Left knee: white blood count, 80,000 cells per cubic millimeter of which 88 per cent were polymorphonuclear neutrophils, 4 per cent lymphocytes, 8 per cent monocytes; serum sugar, 67 milligrams per 100 cubic centimeters and synovial-fluid sugar, 35 milligrams per 100 cubic centimeters; mucin precipitation was very poor.

Right knee: white blood count, 28,150 cells per cubic millimeter, of which 91 per cent were polymorohonuclear neutrophils, 4 per cent were lymphocytes, and 5 per cent were monocytes; serum sugar, 56 milligrams per 100 cubic centimeters and synovial-fluid sugar, 51 milligrams per 100 cubic centimeters; mucin precipitation was very poor.

The findings in the left knee as compared with those in the right knee were interpreted as showing an infectious arthritic response presumably secondary to the previous injection. Accordingly he was treated with antibiotics; and, within a few days, the left knee showed progressive clinical signs of improvement, and his fever subsided. Cultures and smears of synovial fluid failed to reveal the specific organism, but it was not felt that this ruled out an infectious arthritis.

Serial analyses on January 30, 1958, of synovial fluid aspirated from the left knee following antibiotic therapy showed the following: white blood count, 63,200 cells per cubic millimeter of which 86 per cent were polymorphonuclear neutrophils, 5 per cent were lymphocytes, and 9 per cent were monocytes; mucin precipitation was very poor.

On February 6, 1958, synovial fluid from the left knee revealed: white blood count, 24,050 cells per cubic millimeter of which 90 per cent were polymorphonuclear neutrophils, 7 per cent were lymphocytes, and 3 per cent were monocytes; serum sugar, 58 milligrams per cubic centimeter and synovial-fluid sugar, 45 milligrams per 100 cubic centimeters; mucin precipitation was poor.

At the time of discharge two weeks later, swelling, warmth, and discomfort in the left knee were much the same as those in the right knee.

It was felt that this patient had rheumatoid arthritis complicated by an iatrogenic infectious arthritis. Without noting the early synovial-fluid-analysis discrepancies, proper treatment might have been delayed and permanent damage produced.

DISCUSSION

The application of these tests on synovial fluid is of particular value in the differential diagnosis of monarticular arthritis. When there is a history of trauma or a suspicion of degenerative arthritis which may be misleading, little difficulty is encountered in separating the more severe inflammatory reactions seen in the Group II patients from the traumatic or degenerative reactions seen in Group I patients. Thus, with the results of these three tests, primary inflammatory disease can usually be separated from traumatic sequelae, and further clues to the causation of the inflammatory process may be found.

Close inspection of the synovial-fluid smear made for leukocyte differential count and the use of bacterial stains when indicated may occasionally demonstrate the infecting organism. For example, a case of mycotic arthritis was diagnosed in our laboratory by this technique in a patient with a previously undiagnosed generalized disease. The presence of infectious arthritis frequently can be demonstrated by evaluation of the leukocyte count and the sugar difference. Difficulties in culturing bacteria from synovial fluid (especially the gonococcus) are common, and a negative culture does not exclude infectious arthritis.

When one develops the habit of aspirating synovial fluid from involved joints in which the cause of disease is not known, a significant number of unsuspected diagnoses will be made and made early in the course of the disease. The technique can eliminate unnecessary treatment and, possibly, the necessity of an arthrotomy. We do not want to give the impression that this series of tests will suffice in the diagnosis in all cases of arthritis. The need for open synovial biopsy will still exist in some instances. This is especially true where tuber-

culous arthritis is strongly suspected and a six-week to ten-week delay for culture is not advisable.

CONCLUSIONS

Synovial-fluid analysis is of practical importance in the differential diagnosis of joint disease. The separation of cases of severe inflammatory response from those of basic traumatic and degenerative etiology can be readily accomplished. With the aid of these tests, early diagnosis of the nature of the arthritis is often possible.

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Traumatic Cyst in the Hip Joint

A Case Report

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Traumatic cyst of the joint is rare, both as to locality and mechanism of occurrence. The case presented is most probably one of post-traumatic inflammation and distention of the bursa iliopectinea (subpsoas bursa). The bursa may be connected by a narrow duct with the hip joint, as it was in our patient. The communication was proved at surgery and by roentgenogram. Chemical irritation as well as friction gradually turned the bursa into a cyst which, attaining considerable size, exerted pressure upon the surrounding area.

A survey of available European literature on orthopaedics and surgery and perusal of publications from Anglo-American sources yielded no similar case.

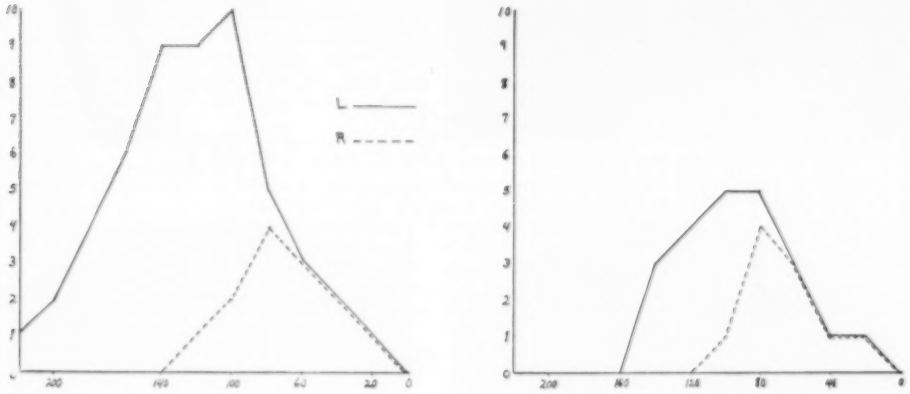

FIG. 1

G.I., a workman, forty-seven years old, was hospitalized from April 28 to August 4, 1956. While the patient had been working on tunnel construction in 1936, fragments from a collapsing rock had hit him in the region of the groin and left arm. The trauma was so severe that he had lost consciousness. A large hematoma developed in the areas of the left groin, lower quadrant of the abdomen, and upper third of the left thigh. Roentgenographic examination showed no damage to bone. After hospital treatment of two and one-half months the patient had noticed reduced mobility in the left hip joint and slight difficulty in walking. Since January 1956, without occurrence of any further trauma, the patient had constant pain in the region of the left hip which spread down the medial side of the leg. The pain made walking difficult but diminished with rest. When walking, he would feel at times a burning sensation, especially in the shin and foot. With the onset of pain he noticed a gradually increasing growth or protuberance under the skin of the left groin. He was admitted to the hospital for treatment of these complaints.

The patient's general physical condition was normal. In the left inguinal region beneath the middle portion of the inguinal ligament a growth (nine by eight by seven centimeters) under the skin was palpated. It was of firm, elastic consistency, not easily movable, and well detached from the surrounding tissues. Intermittent pulsation was noted in the area. On palpation of the lateral side of the ball-shaped growth an increased pulse of the femoral artery was felt. A prolonged systolic murmur was heard on auscultation. Flexion of the hip joint was limited and painful; inward rotation was more limited and painful than flexion. Other movements of the hip joint were normal. Elevation of temperature of the left foot over that of the right was noted.

Laboratory findings were within normal limits. The pelvis and left hip joint were nor-

FIG. 2

FIG. 3

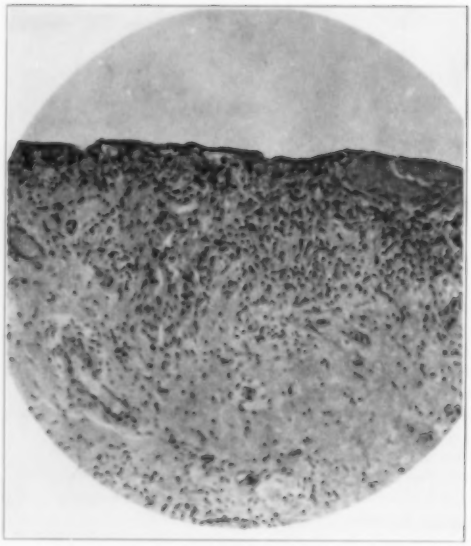

FIG. 4

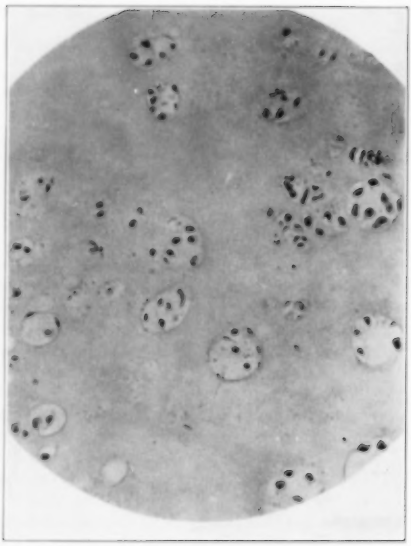

FIG. 5

mal as seen roentgenographically. The oscillogram indicated a markedly increased pulsation of the arteries in the left lower limb, especially in the thigh (Fig. 1). On July 12, 1956, aortography demonstrated lateral displacement of the femoral artery and vein on the left side without further pathological change in the blood vessels (Fig. 2).

Surgery was performed on July 23, 1956. A longitudinal skin incision was made above the growth in the left groin. The femoral artery and vein were separated from the growth and displaced medially by means of a rubber tube. Beneath the psoas muscle there ap-

peared a ball-shaped cystic formation sharply delimited from the muscles, its base directed toward the hip joint. The cyst was separated from the surrounding tissues and it was noted that its median part was joined to the superior ramus of the pubis. The base of the cyst narrowed and ran laterally between the iliofemoral ligament and the pubocapsular ligament onto the acetabulum (Fig. 3). Puncture yielded a mucous, yellowish-green liquid. The capsule was dissected: its cavity contained large numbers of rice bodies, ranging in size from four to six millimeters. The loose bodies were of a whitish translucent appearance. The base of the cyst ended in a narrow duct leading toward the hip joint. The cyst was completely stripped off, the opening at the bottom between the ligaments being closed with sutures. Penicillin (800,000 units) and streptomycin (one gram) were applied locally. The wound was then closed in the usual manner; no rubber drain was used.

FIG. 6

The specimen obtained was a cystic formation nine by eight by seven centimeters. Its walls were about three millimeters thick interspersed with some cartilaginous tissue. The inner surface of the cyst was smooth.

The postoperative course was uneventful. Microscopic examination of the contents revealed no abnormality. Two kinds of tissue were differentiated histologically. The lesser part of the material consisted of compact fibrous connective tissue ending in a straight, slightly puckered surface. This tissue contained under its surface numerous spindle cells, radially oriented capillaries, and a slight number of lymphocytes. Single spindle cells on the surface itself behaved like epithelial cells. The structure greatly resembled that of a mucous sac (Fig. 4). The larger part of the tissue was hyaline cartilage, the turgid cells of which were grouped or irregularly scattered in a homogeneous intracellular substance. Single particles of cartilage were surrounded by an envelope of connective tissue and a zone of chondroblast-like cells (Fig. 5).

On August 3, 1956, a postoperative roentgenogram of the left hip raised the question of whether or not there was a defect in the middle third of the convexity of the acetabulum. The trabecular structure and the quantity of calcium contained in the head of the femur were normal (Fig. 6). On August 4, 1956, the patient was discharged. The wound had healed cleanly. Abduction and flexion of the left hip joint were slightly reduced. Rotation of the joint was painless.

On April 1, 1957, a roentgenogram showed the left hip joint to be normal. Follow-up examination after a lapse of eight months demonstrated movements of the hip joint to be painless. A slight limitation of flexion persisted, but the range of other movements was maximum. The patient walked without limping and was employed at hard physical labor.

DISCUSSION

Some bursae, either congenital or acquired, are connected by a duct with the nearest joint cavity. The bursa iliopectinea (subpsoas bursa) is connected by a canal with the hip joint in 10 per cent of all cases. It is located beneath the psoas muscle, between the iliopectineal eminence and the tendon of the psoas. The duct passes between the iliofemoral and pubocapsular ligaments. Similar cases of bursae in the shoulder or knee joint are known. Communication between bursa and joint may be acquired, usually occurring in consequence of trauma or traumatic inflammation.

In differential diagnosis, consideration should be given to loose bodies in connection with chondromatosis of the joints, arthrosis deformans, and osteochondritis dissecans. In the present case, the anamnestic, clinical, and roentgenographic aspects ruled out consideration of these disorders.

Most bursae are noticed neither by the patient himself nor by the examining physician. It is only when the fluid contents and the loose bodies in the

bursa increase or its walls thicken that difficulties appear and diagnosis is established.

The prognosis for surgical treatment is favorable. It consists in total excision of the bursa or synovial membrane. Incomplete removal of the bursa shortly leads to recurrence.

Based on surgical, roentgenographic, and histological findings, it was considered that the patient had traumatic iliopectineal bursitis and that the bursa was anatomically connected with the hip joint. The internal pressure in the cyst caused disturbances in the joint. Pressure upon the surrounding area, especially upon blood vessels and nerves, effected disturbances in innervation and caused vegetative difficulties, for instance, sensation of heat in the foot. The differential diagnosis in this case was not clear since the cystic enlargement following trauma with systolic murmur, pulsation, and vegetative vascular phenomena resembled traumatic arteriovenous fistula. The diagnosis was clearly established by aortography.

Non-Union of a Fracture of the Anterior Superior Process of the Calcaneus

CASE REPORT

BY JACK LEVINE, M.D., ABEL KENIN, M.D., AND MORTON SPINNER, M.D.,
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Increased interest in fracture of the anterior superior process of the calcaneus in recent years has been evinced by the fact that three papers discussing this fracture have appeared in the American literature since 1951 [3,4,6]. It is the consensus that these fractures usually heal in a month or two after immobilization with a plaster cast or simple adhesive strappings [1,2,4,6]. Piatt described a case of non-union of a fracture of the anterior superior process of the calcaneus, but noted that there was "little discomfort except on the extremes of plantar flexion of the injured foot." The following case is of interest since it presents a fracture of the anterior superior process which did not unite and the patient remained symptomatic until the ununited fragment was removed.

A housewife, thirty-seven years old, was first seen on June 17, 1954, two months after having injured her left foot by twisting it as she stepped off a bus. Roentgenograms made shortly after the injury, April 18, 1954, were reported negative for fracture or dislocation (Fig. 1). Her foot and ankle were strapped but because of persistent pain and swelling, she was unable to bear any weight at all on her left foot for four weeks. She walked with the aid of crutches. Later, partial weight-bearing was permitted with an elastic bandage support on her foot. However, because of pain, her limp persisted. She further noted that swelling was increased at the end of a day but would subside almost completely by morning.

At examination on June 17, 1954, it was found that the patient walked with a marked limp favoring her left lower extremity. There was three-quarters of an inch of atrophy of the left calf. There was extreme tenderness to palpation of the sinus tarsi. Inversion of the foot and rocking of the subtalar joint caused pain in the same area. These movements were only mildly restricted. There was no limitation of motion in the ankle joint, but extremes of plantar flexion and dorsiflexion also caused similar pain. Roentgenograms made on June 17 (Fig. 2) revealed slight displacement of a fragment comprising the anterior superior process of the calcaneus. There was some increase in the density of the fragment as compared with that of the surrounding bone. It was felt that more rigid immobilization at this time, two months after the injury, would serve

FIG. 1

April 18, 1954. Lateral roentgenogram of the left foot which initially was read to be negative but on further scrutiny was seen to demonstrate fracture of the anterior superior process of the calcaneus.

FIG. 2

June 17, 1954. Oblique roentgenogram of the left foot revealed the slightly displaced fragment of the anterior superior process of the calcaneus with somewhat increased density as compared with that of the surrounding bone.

no useful purpose. Accordingly, the patient was advised to continue strappings and physical therapy. However, her symptoms continued undiminished and subsequent roentgenograms showed increasing density of the bone fragment (Fig. 3). On November 8, 1954, an exploration of the sinus tarsi was carried out. The loose fragment of bone was readily identified. There was no evidence of bone union. Part of the bifurcate ligament was still attached to the loose fragment. The fragment was removed without difficulty, and the foot was immobilized in a plaster cast for two weeks after the operation.

Following this, inversion strappings were continued for two weeks more. The patient then proceeded to make a rapid recovery. Within two months, there was complete disappearance of foot spasm and limp. She was seen most recently on November 15, 1957 (Fig. 4). At this time, there was a normal gait and complete range of motion in the subtalar and mid-tarsal joints. The patient had no symptoms referable to her foot.

DISCUSSION

This case is of interest since it represents the first reported case of non-union of an anterior superior process of the calcaneus which required surgery for relief

FIG. 3

October 22, 1954. Oblique roentgenogram of the left foot revealed increased density in the fracture of the anterior superior process with further displacement.

FIG. 4

November 15, 1957. Oblique roentgenogram of the left foot revealed some sclerosis in the portion of the calcaneus adjacent to the area where the fragment of the anterior superior process of the calcaneus had been removed.

of symptoms. The patient had persistent pain until the fragment was removed. She then went on to an uneventful recovery. A fracture of the anterior superior process of the calcaneus can be overlooked in the routine lateral roentgenogram of the foot. Oblique roentgenograms of the foot are essential in a complete study especially in making a diagnosis of fracture of the anterior superior process of the calcaneus.

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Proceedings

THE RUSSELL A. HIBBS SOCIETY

The Eleventh Annual Meeting of the Russell A. Hibbs Society was held on May 28 and 29, 1958, at Indiana University and Medical Center, Indianapolis, Indiana, with Dr. J. Neill Garber presiding. Following the business meeting, the following new members were elected: Dr. Sherman Coleman, Salt Lake City, Utah; Dr. James D. Jones, Lynchburg, Virginia; Dr. Virgil May, Richmond, Virginia; Dr. George Sheer, St. Louis, Missouri, and Dr. William Schnute, Chicago, Illinois.

Dr. William Waldrop, Oklahoma City, Oklahoma, was unanimously elected President of the Russell A. Hibbs Society, and Dr. Nicholas J. Giannestras, Secretary-Treasurer. The next meeting of the Society will be held in Oklahoma City, Oklahoma, in May 1959.

The two guest speakers at this meeting were Mr. Roland Barnes of The Western Infirmary, Glasgow, Scotland, and Dr. Philip D. Wilson of The Hospital for Special Surgery, New York, N. Y.

Summaries of the papers presented follow:

Transference of the Iliopsoas Muscle for Hip Abductor Paralysis. Dr. George J. Garceau [1] and Dr. Robert J. W. Kinzel reported results of the transference of the iliopsoas in poliomyelitic patients with abductor paralysis of the hip in whom there was considerable abduction lurch or painful instability or both of the hip joint. Good to normal power should be present in the iliopsoas along with some remaining hip-flexor power in the sartorius or rectus femoris before the muscle is transplanted through an iliac aperture at the iliac fossa into the greater trochanter of the femur. The youngest patient operated on was eight years old; the oldest was twenty-six. Seventy-seven per cent showed gait improvement; in 86 per cent of those with external rotation of the lower extremity (53 per cent of the total number of cases) improvement was obtained.

Dislocation of Talus. Dr. T. A. Brady [2] presented a series of fractures of the neck of the talus with posterior dislocation of the body. Immediate open reduction with primary subtalar fusion was done through a posterior medial incision directly over the displaced body of the talus. In total dislocation of the talus, replacement was facilitated by osteotomy of the fibular malleolus. A plea was made to save the displaced bone fragments unless they are grossly infected. Avascular necrosis inevitably results from this injury but disability was minimal.

Recovery from Hip Prosthesis. Dr. J. N. Garber [3] and Dr. R. W. Lambert presented two distinct operative procedures for the recovery of the disabling, painful prosthetic hip. These procedures are not new or original but are revivals of procedures used successfully in past years for other conditions. Their usefulness was recently recognized due to anatomical considerations in recovery from pain caused by a hip prosthesis.

The authors presented five unselected cases of painful hip due to a prosthesis. The classic Whitman reconstruction was performed in two patients with Judet prosthesis and, in one patient, with a Smith-Petersen cup arthroplasty. The Colonna reconstruction, followed in two months by high subtrochanteric osteotomy to create an artificial coxa femoral angle, was performed in two patients with a larger intramedullary femoral-stem prosthesis. The patients were all free of pain at last examination. There was no correlation between the procedure and the amount of motion retained in the recovered hip, since, in each group, one patient required arthrodesis and the others retained various degrees of motion. Intrapelvic unilateral obturator neurectomy was of temporary value in the treatment of painful prosthetic hip. The average time until improvement was eighteen months.

Treatment of Pott's Paraplegia. Mr. Roland Barnes [4] discussed paraplegia as the most lethal complication of Pott's disease. In the early stages of the disease the cord is compressed by a tense abscess, sequestrum, or necrotic disc, whereas when paraplegia occurs late—perhaps many years after apparent healing of the disease—the cord is often stretched over a sharp gibbus.

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3. 23 East Ohio Street, Indianapolis 4, Indiana.
4. The Western Infirmary, Glasgow, Scotland.

About one half of the patients, treated conservatively, recover completely; a quarter die; and the remainder have residual palsy which is often severe. Operative treatment must be judged by its ability to prevent residual palsy and its potential fatal result. Because of this, laminectomy and spine fusion are no better than conservative treatment. Operation will be successful only if it relieves pressure on the front of the spinal cord.

In an early mild case of paraplegia, relief of pressure may be achieved by draining the abscess and removing the necrotic disc and sequestrum without actually exposing the dura mater. If paraplegia is severe or of rapid onset, prompt anterolateral decompression of the cord by the technique of Pott and Alexander is indicated, followed by an adequate period of rest until the disease is quiescent. In cases of paraplegia of late onset, it is essential that radical removal of the bone spur be performed; on three occasions a second operation was required because the cord was not adequately decompressed at the first intervention.

Three of the seventeen patients died; one under anaesthesia, one from severe Addison's disease, and one from paraplegia of late onset—the first patient in the series. Four of the six patients with early paraplegia and six of the eight patients with late paraplegia recovered completely. Anterolateral decompression is never easy; however, better recognition of the technical difficulties of the operation and their management has led to steady improvement in results.

Tenosynovitis and Related Conditions Involving the Tendon Sheaths. Dr. John B. White[5] presented a classification for the various surgically encountered lesions of the tendon sheaths. The lesions encountered surgically were: circumscribed villonodular tenosynovitis; chronic hypertrophic villous tenosynovitis; chronic adhesive tenosynovitis; granulomatous tenosynovitis; and acute suppurative tenosynovitis. The author discussed representative cases from each of the groups in the classification and reviewed forty-one patients with circumscribed villonodular tenosynovitis. The transition between chronic hypertrophic villous tenosynovitis and circumscribed villonodular tenosynovitis was discussed. The pathogenesis of chronic hypertrophic villous synovitis and tenosynovitis and circumscribed villonodular tenosynovitis was also discussed. The author demonstrated that a single pathogenic factor, trauma, may produce one or all of the lesions classified.

High-Tension Electrical Burns. Dr. John M. Tondra[6] stated that the purpose of his paper was not to discuss the causes of death but to note the results of high-tension electrical burns in the individuals who survive the initial shock.

A summary of the physical facts directly related to the effect of electrical burns was reviewed. This included voltage, amperage, type of current, resistance, path of the current, and individual susceptibility.

The author stressed the progressive nature of the wounds caused by electrical burns, and differentiated between two types of burns, contact and arc burns. He also described systemic complications such as lower nephron nephrosis resulting from acute burns. A characteristic injury associated with high-tension electric shock is fracture-dislocation of the humerus due to severe tetanic contracture of the muscles. Late complications of the acute burn such as cephalomalacia and myocardiomalacia also might occur. There are important residual findings in previously burned patients such as localized muscular atrophy and weakness of the involved extremities months after the accident.

Therapy of electrical burns is considerably different from that of thermal burns. The conservative approach in the treatment of electrical burns is recommended because of the progressive nature of the injury.

Dr. Tondra stressed that it is important to remember that the burn itself is not the only problem entailed; secondary complications occurring sometime after the initial shock may be lethal or permanently disabling.

Surgery in Cerebral Palsy. Dr. Carl Martz[7] felt that in surgical treatment of cerebral palsied patients, attention should be directed to: (1) the loss of flexibility demonstrated by contractures and imbalances; (2) loss of power appearing as weakness or complete paralysis; (3) deformities arising from contractures of the fascia, capsules, muscle, or maldevelopment of bone; and (4) loss of skill obvious in disorders of gait and manual work. The general principles involved are correction of deformity, motor transfer, postural stabilization, and growth control.

The goal in surgery of the lower extremities has been to secure proper alignment, stabilization, and normal reciprocal pattern of the hip, knee, and ankle. This has not been readily accomplished, and the author felt that surgeons should do neurectomies selectively. Tendon

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transfers should be done in phase, and stabilization should be performed to attain the best possible posture and muscle balance that can be achieved by training and bracing.

The time of surgery is extremely important and one must recognize that diplegic posture of cerebrate rigidity will change after several years to anthropoid posture or jump posture, with flexion of the hip and knee and toe stance. Braces and muscle-training are essential in the program when surgery is included. Neurectomies and tendon transfers are performed on patients in the younger age groups; osteotomy has mainly been restricted to patients between the ages of ten and fourteen.

The author discussed seven common methods of correcting or controlling equinus deformity in cerebral palsy; none are uniformly successful. All have specific indications:

1. Subcutaneous Achilles-tendon lengthening is occasionally more complete than necessary, but more often is insufficient and complicated by residual scarring.

2. Open Achilles-tendon lengthening has been practiced in the manner of Hibbs. This procedure has been performed most often and also with the most gratifying results. The technique consists of a curved skin incision, a lateral incision through the tendon sleeve, a coronal section of the tendon itself with the slick surface near the distal portion, minimal suture buried in the tendon, closure of the sheath, and application of a plaster cast to be worn for three to four weeks as suggested by John Hunter.

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Side Plate for Subtrochanteric Fracture. Dr. William H. Norman [8] outlined a simplified procedure for the open method of hip nailing. It consists of using the regular operating table, a simple cassette holder, one portable x-ray machine, and polaroid films. It permits easy access to the fracture, control of the lower extremity, eliminates the difficulty in obtaining good lateral roentgenograms, and materially shortens the procedure.

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Epiphyseal Fracture Separation at the Proximal End of the Humerus. Open Reduction in Three Cases. Dr. Thomas Horwitz [9] presented the cases of three male patients, one aged twelve and two aged sixteen, with epiphyseal fracture separation at the proximal end of the humerus. The fracture involved the posterior third of the proximal end of the metaphysis which remained attached to the capital epiphysis, the shaft being displaced proximally and anteriorly to the head fragment. In the first patient the injury was two weeks old and sufficient union had occurred to prevent closed reduction. In the second and third patients both fractures were recent; closed reduction was attempted with insufficient results in both instances, in the opinion of the operator. In the third patient, continuous traction was utilized for several days with the injured arm in pivotal position without success.

An incision through the deltoid and pectoralis major muscles and subperiosteal dissection of the soft tissues anteriorly exposed the fracture site; every effort was made to keep the lateral, medial, and posterior tissues intact. In all three patients a tight pectoralis major was a factor in preventing reduction of the fracture. Since the tendon of the pectoralis major was divided at its insertion, it facilitated levering the proximal end of the shaft fragment under the proximal fragment, but the author noted that, even under these circumstances, reduction was not maintained unless the arm was elevated in the frontal plane, serving to lock the distal fragment securely under the proximal fragment. The reduction was now so secure that internal fixation was not required, and the degree of rotation was usually neutral. In the third patient, the author felt that an interposing long bicipital tendon may have been a factor in preventing closed reduction. This tendon was divided proximally and attached to the coracoid process. External fixation, in a plaster spica shoulder cast, with the arm in the elevated or pivotal posi-

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9. 23 East Ohio Street, Indianapolis 4, Indiana.

tion in the frontal plane, was maintained for three months. The author concluded by saying that excellent anatomical and functional results were obtained in each patient.

The Early X-ray Diagnosis of Acute Hematogenous Osteomyelitis. Dr. Joseph L. Morton [10] reported that deep-seated swelling of muscle with contiguous oedema surrounding a bone or joint following a day or two of fever is characteristic of acute coccal osteomyelitis. Cellulitis, lymphangitis, and erysipelas are differentiated by the lack of deep circumferential swelling about the bone and muscle, fusion of the skin and superficial fascia, and presentation of deep fascial planes, at least on one side. Severe deep trauma is the only lesion likely to confuse the roentgenologist but this can easily be recognized by history or clinical examination. The author felt that vigorous treatment at this stage of the disease could abort the process without roentgenographic osseous involvement. Resistance is greatest in the patient early in the course of the disease and with adequate continuous therapy there is little chance for the organisms to become resistant to antibiotics. The length of therapy is determined by the roentgenographic appearance and continued until all visible deep thickening and oedema have subsided. This may require a month or more.

Dr. Morton pointed out that textbooks continue to state that roentgenographic diagnosis is impossible within the first two weeks of the disease, despite Ferguson's opinion to the contrary held for the past twenty years. This encourages pediatricians and general practitioners to doubt the validity of early diagnostic roentgenograms and leads to delay in therapy until too late to prevent sequestration and other complications such as septicaemia, pneumonia, lung abscess, or empyema.

Two cases, both diagnosed early as acute hematogenous osteomyelitis, were presented. The first patient was successfully and continuously treated for more than a month without development of osseous change. The second patient was transferred by his parents to another hospital after a few days of good response to therapy. There, "no evidence of osteomyelitis" was reported. Relapse occurred followed by all of the above mentioned complications. The first patient was treated mainly in the out-patient department. The second patient required more than six months of hospitalization at public expense.

Some Vascular Problems of Interest to Orthopaedists. Dr. Harris B. Shumacker [11] pointed out that one disastrous, but fortunately rare, complication of operations for protruded intervertebral disc is injury to the great vessels within the abdomen. This should be suspected whenever excessive bleeding occurs or unexpected shock develops. It should be recognized early and treated immediately after completion of the laminectomy by laparotomy and repair of the injured vessels. The author reported the case of a woman who, during such an operation, sustained an injury to the right common iliac artery and the vena cava, resulting in a large arteriovenous fistula. Almost immediately severe heart failure developed and the patient was incapacitated until the true nature of her heart failure was recognized two and a half years later when she was first admitted to this hospital.

The problem of deep venous thrombosis continues to be an occasional complication in the treatment of orthopaedic injuries. Functional venographic studies have demonstrated that thrombosed femoral or external iliac veins apparently invariably recanalize. Contrary to former beliefs, these recanalized veins propel blood in the proper direction toward the heart during active muscular exercise. As a consequence, it is felt that they should not be sacrificed, and no deep vein ligations are being done in this clinic. The results of nonoperative treatment have been very gratifying. Operations are reserved for chronic indurated ulcers which require deep, wide excision and skin-grafting. With regard to the management of acute deep venous thrombosis, it appears that in the future we may have agents which can be used safely and effectively to lyse the clots. Among these are a purified streptokinase and plasmin. Neither is available for clinical use at the present time, but work being done in other clinics suggests that, if such materials ever become available, they may be of considerable aid.

Dr. Schumacker feels that many patients with obliterative disease affecting the aorta and the iliac vessels seek orthopaedic consultation because of pain in the hips or back. The nature of this abnormality is easily recognized because pain occurs only on walking and ceases with momentary rest. There is also the characteristic absence or diminution of peripheral pulses. The surgical treatment of such conditions by excision and grafting or by by-pass grafting procedures is gratifying.

Basic Weight-Bearing Functions in the Foot. Dr. John L. Holmes [12] discussed his study of the effects of simple application and of weight-bearing muscle actions in normal and abnormal feet. He tested unpreserved foot specimens and a foot model capable of imitating foot deformities and stance positions. The author found that weight-bearing actions of muscles controlling the foot are not always the same as the generally accepted non-weight-bearing

10. 120 West Fall Creek Parkway, Indianapolis 7, Indiana.
11. 1100 West Michigan Street, Indianapolis 7, Indiana.
12. Indiana University Medical Center, Indianapolis 7, Indiana.

muscle actions. For example, in the non-weight-bearing position, the triceps surae always supinates the subtalar joint and is responsible for the varus position. However, during weight-bearing the triceps surae may put a normal foot in slight valgus position in a neutral standing position. During weight-bearing it may put the foot of a patient with valgus foot deformity in valgus position. Finally, it may be a powerful cause of weight-bearing varus position in a patient with varus foot deformity. Another example mentioned by the author was the tibialis posterior. Although the posterior tibial muscle alone produces subtalar varus position, in both non-weight-bearing and weight-bearing, it produces ankle equinus deformity in non-weight-bearing and calcaneus in weight-bearing. Other examples of unexpected differences between weight-bearing and non-weight-bearing functions of muscles were the peronaeus longus and the short plantar muscles.

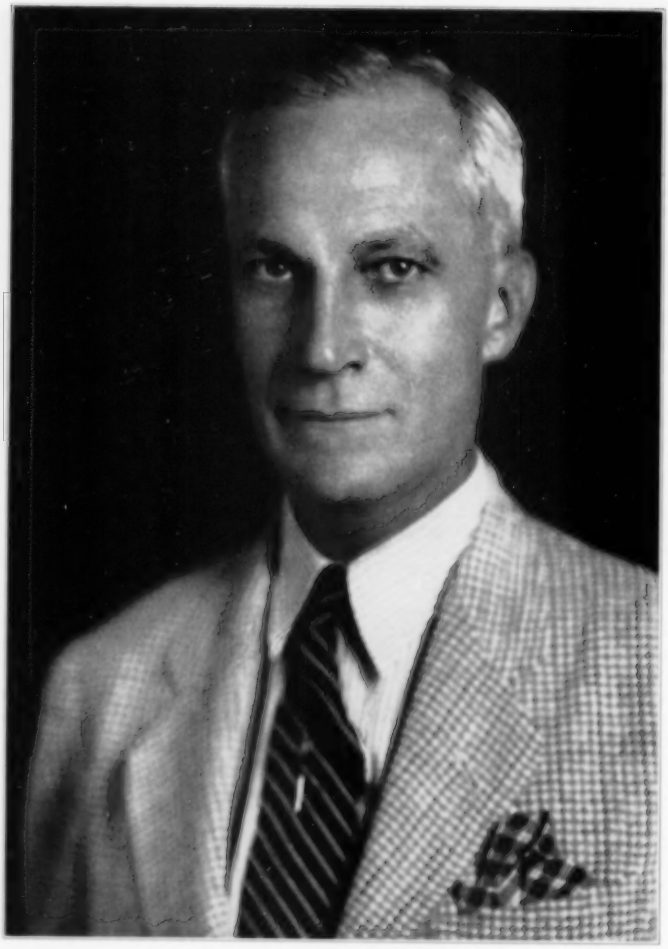
The author also pointed out that the extensor hallucis longus is responsible for subtalar varus position in the normal foot and in feet with varus deformity in both non-weight-bearing and in weight-bearing. However, it may place the foot with valgus deformity in valgus position.

Basic reports in the anatomical literature indicate that the human foot is a weight-bearing pronation structure. This study indicates that such is true for the normal foot and the foot with valgus deformities in neutral and valgus standing positions. However, this study confirms the clinical impression of many orthopaedic surgeons that the varus foot, or the normal foot in extreme varus stance, is a supination weight distributing structure.

Considering either the weight-bearing response of the triceps surae or the effects of simple weight-bearing without muscle, the author felt that the result tends to be subtalar varus position with extension deformity of the lateral portion of the fore part of the foot, or rocker-bottom deformity, or it tends to create subtalar valgus position with flexion deformity of the lateral portion of the fore part of the foot, or lateral cavus deformity of the fore part of the foot.

Weight-induced subtalar pronation is resisted predominately by the plantar ligaments of the medial portion of the fore part of the foot rather than by the deltoid ligament, if the foot is normal and in neutral standing position. The deltoid ligament resists weight-bearing pronation only with a marked valgus deformity. In non-weight-bearing, only the deltoid ligament resists subtalar pronation.

Pes Cavus. Dr. George J. Garceau [1] stated that in 1956 he first reported experience with selective plantar muscle denervation. At present this operation has been performed on over 100 patients. The operation is indicated in congenital and paralytic pes cavus. It is also useful in residual deformity of congenital club-foot. To obtain best results the operation should be performed before growth is complete. The author has obtained satisfactory results in about 90 per cent.



BERNARD HEWITT KYLE
1887-1958

BERNARD HEWITT KYLE, M.D.

Dr. Bernard Hewitt Kyle died suddenly at his home on August 22, 1958, six weeks after having had a coronary occlusion. He is survived by his wife, Putnam Watkins Kyle, and a daughter, Jimmie Kyle.

He was born in Nelson County, Virginia, on April 17, 1887, the son of Ella Agee and Joshua Warner Kyle. He graduated from Virginia Polytechnic Institute and took his medical training at the University of Virginia and the Medical College of Virginia, from which he graduated in 1911. He entered general practice in Lynchburg, Virginia.

Dr. Kyle saw combat action in World War I with the 12th Field Artillery of the Second Division. He was cited for heroism and exceptional gallantry under fire in both French and United States Army Division Orders. After the war ended, he was assigned to duty with the University of Virginia Base Hospital. It was during this period that he realized the importance of orthopaedic surgery and developed an intense interest in it. He gave up his general practice and took postgraduate work at the Children's Hospital and Harvard Medical School. He returned to Lynchburg to become an orthopaedic specialist. He thus became the first orthopaedist in this central area of Virginia. The tedious job of making orthopaedics a recognized specialty by the physicians, hospitals, and patients fell on his shoulders. The necessary recognition was accomplished in time, making the path an easier one for the orthopaedists who followed.

He became a Fellow in the American College of Surgeons in 1924 and a member of The American Academy of Orthopaedic Surgeons on January 9, 1934.

Dr. Kyle was appointed orthopaedist for the Norfolk and Western Railway in Lynchburg and he was active in the Junior League Crippled Children's Clinics. He also took an active interest in the Virginia State Crippled Children's program and held clinics for years at Farmville, South Boston, Bedford, Lexington, Covington, and in Amherst County. He was a member of the active staff of Virginia Baptist Hospital, Lynchburg General Hospital, and Memorial Hospital, and a consultant for the Lynchburg Training School and Hospital.

During World War II, he was chief of the emergency medical department of the Lynchburg Office of Civil Defense and a member of the Procurement and Assignment Service for Physicians. He also served on the Military Induction Board for this area.

Throughout his long and active career, his work was characterized by an intense interest and a stern discipline which set him apart from the ordinary. His enthusiasm for orthopaedics was overwhelming. His presence will be sorely missed by his friends, associates, and colleagues in the medical profession, as well as by his many patients, for years to come.

B. K. M.

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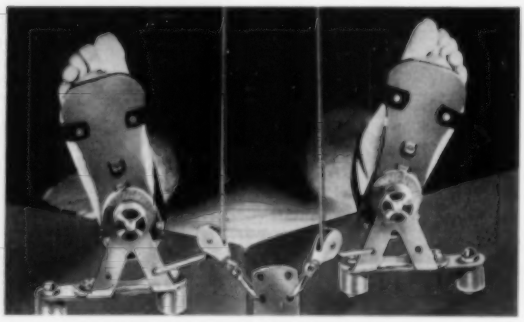

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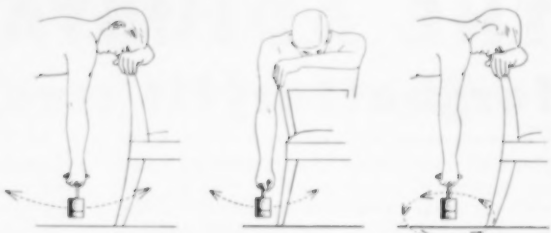

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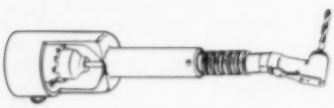

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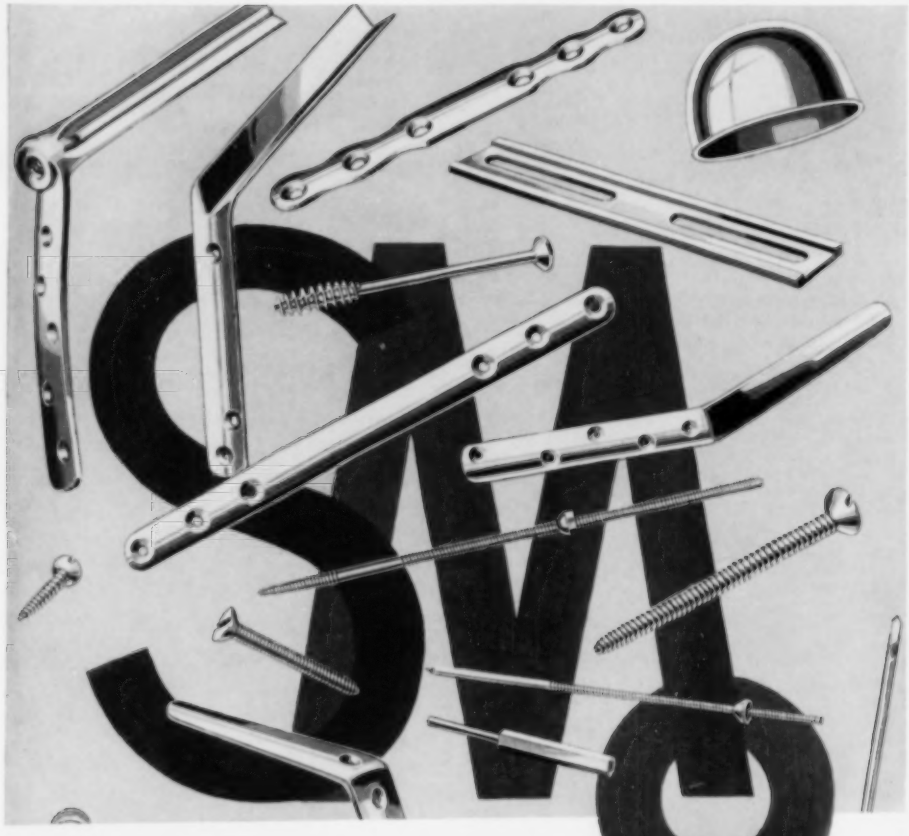

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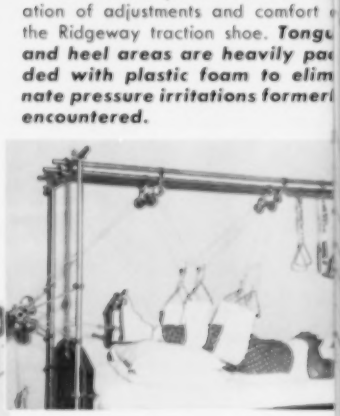

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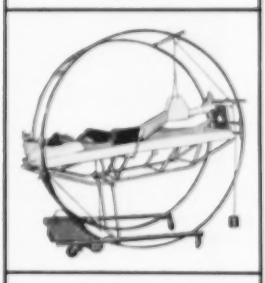

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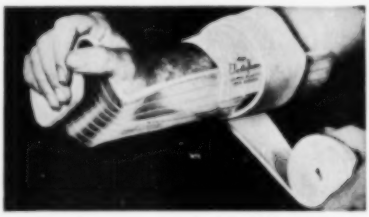

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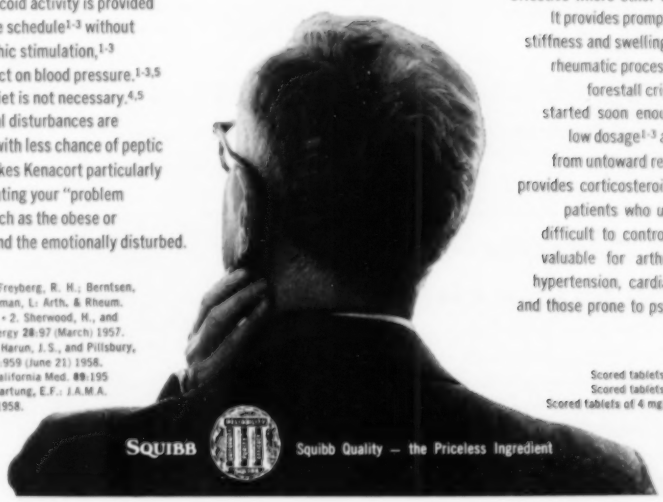

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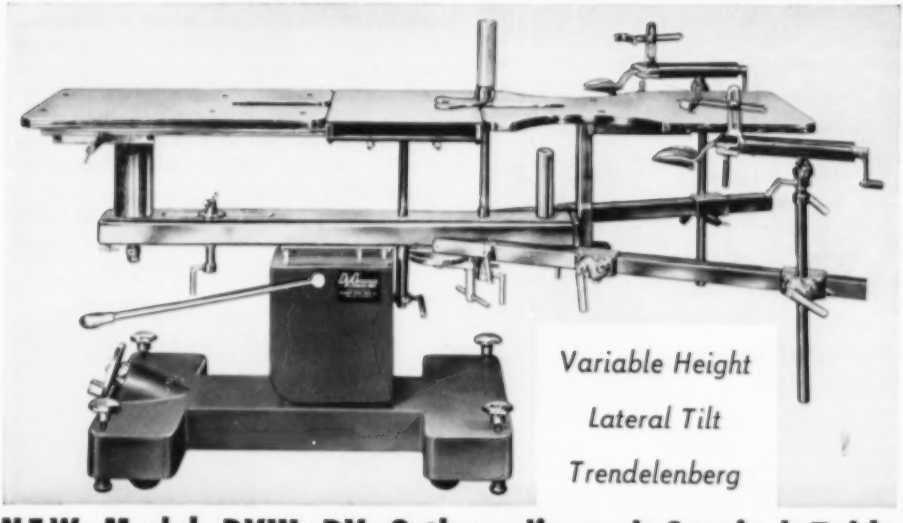

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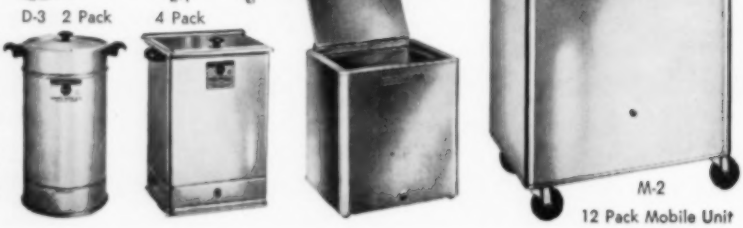

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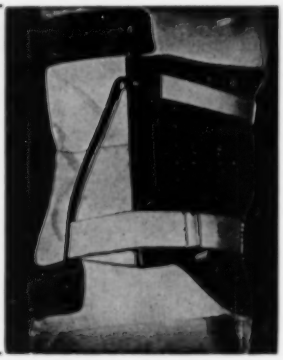

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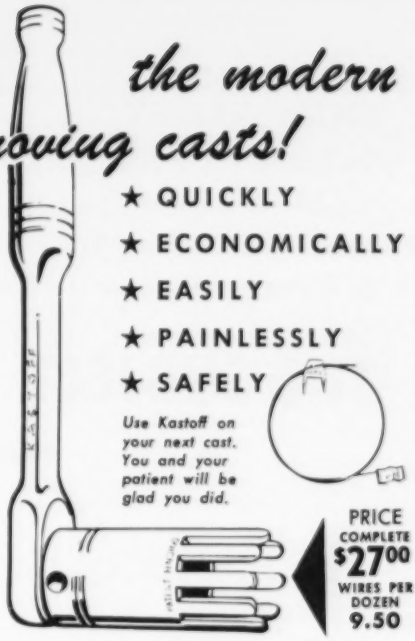

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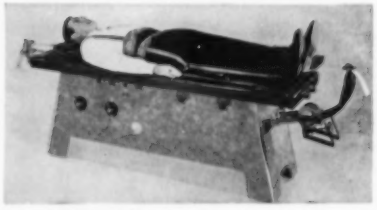

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